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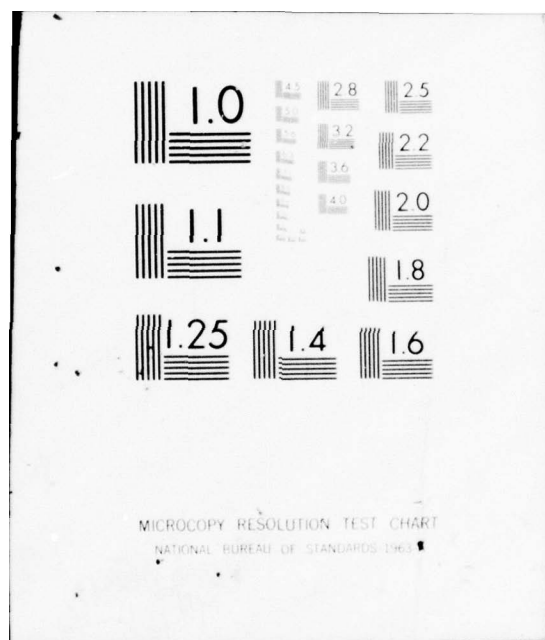
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TECHNICAL REPORT S-77-1

INVESTIGATION OF CONSTRUCTION TECHNIQUES FOR TACTICAL BRIDGE APPROACH ROADS ACROSS SOFT GROUND

by

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February 1977

Final Report

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20. ABSTRACT (continued).

Item 5 was a control item consisting of 14 in. of crushed stone placed directly on the soft subgrade. It had developed an 11-in. rut after 200 coverages of traffic.

Item 1 consisted of an M8A1 mat road that was placed on and tack welded to parallel mat runners placed along the truck wheel paths. The runners were very effective in strengthening and anchoring the mat road over the soft subgrade. This item withstood 54,000 coverages with no damage.

Item 2 contained standard 1-ft-thick commercial wire gabions, filled with 3- to 7-in. rock, and surfaced with 2 in. of crushed stone. The performance of this item was extremely good. After 54,000 coverages, the average rut depth was only 7 in.

A major finding of this investigation was the potential use of sand-confinement systems for base courses over soft subgrades. Both a large-volume confinement system (~~item 3~~) and a small-volume system (~~item 4~~) outperformed the crushed stone control item by a substantial margin.

This investigation also showed that the placement of a fabric or membrane between a soft clay subgrade and crushed stone base can offer substantial savings in the design thickness of a road. Item 6 was identical with the control item except that a pervious polyester fabric was placed between the base and subgrade. This item withstood 2500 coverages before developing an 11-in. rut. This represented a savings in design thickness of approximately 27 percent. Item 7 was also identical with the control item except that an impervious coated nylon membrane (T-16) was placed between the base and subgrade. This item sustained 37,000 coverages before developing an 11-in. rut. This represented a design thickness savings of 48 percent.

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PREFACE

This report was prepared as part of the work authorized by the Office, Chief of Engineers, under Pavement Systems and Lines of Communications, Project No. 4A762719AT40, Task A2, Work Unit 015, "Rapid Construction of Tactical Bridge Approaches," and Task A3, Work Unit 005, "Develop Construction Techniques Compatible with Adverse Conditions." The investigation reported was conducted from September 1975 to June 1976.

Personnel of the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), who were actively engaged in the planning and execution of work that led to the preparation of this report were Messrs. A. H. Joseph, P. J. Vedros, S. L. Webster, and J. E. Watkins. This project was under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, of the Soils and Pavements Laboratory. This report was prepared by Messrs. Webster and Watkins. OCE technical monitor for this study was Mr. R. E. Barnard.

Directors of WES during the conduct of the work and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)

UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	25.4	millimetres
feet	0.3048	metres
square inches	6.4516	square centimetres
pounds (mass)	0.4535924	kilograms
pounds (force)	4.448222	newtons
kips (mass)	453.5924	kilograms
tons (2000 lb)	907.1847	kilograms
ounces (mass) per square yard	33.90575	grams per square metre
pounds (mass) per square foot	4.882428	kilograms per square metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

INVESTIGATION OF CONSTRUCTION TECHNIQUES FOR TACTICAL BRIDGE

APPROACH ROADS ACROSS SOFT GROUND

PART I: INTRODUCTION

Background

1. In many instances, the construction of tactical military bridges is greatly affected by the construction of their approaches. Since rivers flow through low-lying areas which are subject to flooding, bridge approaches will often have to cross floodplains, swamps, or mud flats. The time required to construct approaches is often the controlling factor in selection of a bridge site.

2. Using current technology, the construction of bridge approaches across soft ground requires a great deal of manpower, construction materials, and time. Removal of the soft ground is generally not a practical solution due to effort and time involved. Therefore, approach roads will generally have to be constructed over the soft ground. One problem that develops is that the construction materials used in the foundation keep sinking into the soft ground or allow the soft ground to penetrate into the construction material. This weakens the structure and requires that more fill material be used. This problem often continues during the service life of the structure, and a considerable amount of maintenance must be continuously performed to render the approaches tactically useful.

Objective

3. The objective of this study was to investigate and test the feasibility of various new techniques for constructing approach roads across soft ground from an existing roadnet to a tactical bridge site.

Scope

4. The objective was accomplished by constructing a test section containing seven test items and subjecting the section to accelerated traffic using various loads on a 5-ton* military dump truck. This report describes the materials used, test section, construction techniques, tests conducted and results, and an analysis of the results. Some conclusions are also presented.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

PART II: TEST SECTION

Description

5. The test section was constructed under shelter at the U. S. Army Engineer Waterways Experiment Station (WES) in order to control the subgrade strength and test conditions.

6. A plan and profile of the test section are shown in Plate 1. The test road was 204 ft long and 12 ft wide and consisted of seven test items. Items 2 and 3 (gabion items) were each 27 ft long; all other items were 30 ft long. Item 1 consisted of M8A1 mat, spot welded to runners, placed directly on the subgrade. All other items had a total thickness of 14 in. All items were constructed directly on the heavy clay subgrade, which had an initial strength of 0.7 to 1.0 CBR for a depth of 10 in. The strength of the remaining 14 in. of subgrade below this 10-in. depth ranged from approximately 1.0 to 2.3 CBR. The west and east shoulders of the test section were 4 ft and 3 ft wide, respectively. The shoulder material for items 5, 6, and 7 was the same crushed stone as used in the base course for these items. The shoulder material for items 1 through 4 was sand. All items except item 1 contained a 2-in. wearing surface consisting of the same crushed stone as used in the base course for items 5, 6, and 7.

Materials

Subgrade soil

7. The subgrade of the test section was constructed using heavy clay (CH)¹ having a liquid limit of 68, a plastic limit of 23, and a plasticity index of 45. Classification data for this soil are shown in Plate 2.

Base course

8. Crushed stone. The material used as base in three test items and also as the surface course for six test items was a crushed limestone that met the military base course requirements described in paragraph 7-17

of TM 5-330 (Reference 2). A gradation curve for this material is shown in Plate 2. Also, a crushed limestone ranging in size from 3 to 7 in. was used as base in one test item.

9. Sand. A washed sand (SP) was used as base material in two sand-confinement test items. A gradation curve for this material is shown in Plate 2. The sand contained approximately 6 percent gravel that ranged in size up to 1 in. It was thought that this small amount of gravel would not affect the general performance of the sand.

Landing mat

10. M8A1 steel mat was used in one test item. This light-duty mat was chosen for study because (a) a large amount of M8A1 was stockpiled in the Army inventory and (b) problems with this mat were encountered in Vietnam when it was used for expedient roads over soft soils.

11. M8A1 panels are solid planks, with no pierced holes. The end connections are made by four sliding steel pins, driven into place with a hammer or bar. The side connectors are bayonets and slots. The mat panel is 11.6 ft long, 1.6 ft wide, and weighs 114 lb or 7.5 psf.

Gabions

12. A standard commercial gabion was used in two test items. The gabions were compartmented rectangular containers made of galvanized steel hexagonal wire mesh and are normally filled with 3- to 8-in. stone. They are commercially available in various sizes. The gabions used were 9 ft long, 3 ft wide, and 1 ft deep. Each gabion had three compartments or cells, each 3 ft by 3 ft by 1 ft deep. The gabions were supplied folded and packed in compressed bundles. A soft 0.0944-in. galvanized tie wire was supplied for tying the individual gabions together and also for lacing the lids and sides together. The hexagonal mesh openings were approximately 3 by 4 in. The mesh was made using 11-gage galvanized steel wire.

Plastic tubing

13. A 6-in.-diam corrugated plastic drainage tubing was used to form a sand-confinement system in one test item. The polyethylene tubing had an average wall thickness of approximately 0.050 in. and was supplied in 100-ft coils. This tubing was chosen for test purposes because it was weak in compression. It would probably not be considered for use in actual

road construction. A 50-lb weight placed on a standing empty 1-ft section of tubing caused the tubing to compress 4.5 in. after 5 min. However, a standing 1-ft section of tubing filled with sand held an 8000-lb load and compressed only 1.75 in.

Polyester fabric

14. The fabric used was a spunbonded, needlepunched polyester non-woven called "Bidim." Bidim is registered as a Monsanto trademark in the United States. Test supplies of the fabric were furnished by the Monsanto Textiles Company, St. Louis, Missouri. The fabric used had a weight of 12 oz per sq yd. Some physical properties of a similar "Bidim" fabric weighing 9.6 oz per sq yd are as follows:

Thickness (in.)	0.106
Breaking strength (lb)	
Machine direction	234.3
Cross machine direction	213.0
Elongation at break (percent)	
Machine direction	60.4
Cross machine direction	56.6
Tear strength (lb)	
Machine direction	92.4
Cross machine direction	99.5
Pervious to water	

T-16 membrane

15. T-16 is a neoprene-coated one-ply woven nylon membrane which has been tested and reported on in many studies conducted at WES. Some physical properties of T-16 membrane are as follows:

Weight (oz per sq yd)	18.5
Breaking strength (lb)	
Warp	458.0
Fill	412.0
Elongation at break (percent)	
Warp	29.0
Fill	33.0
Tear strength (lb)	
Warp	48.0
Fill	52.0
Impervious to water	

Design

16. Since the objective of this study was to investigate new techniques for constructing bridge approach roads across soft ground, the test section was designed to allow study of the following:

- a. The performance under traffic of a crushed-stone base placed directly on a soft subgrade.
- b. The effect of a pervious separator fabric placed between a crushed-stone base course and soft subgrade.
- c. The effect of a relatively high-strength impervious membrane placed between a crushed-stone base course and soft subgrade.
- d. The feasibility of using confined sand as a base course material over a soft subgrade.
- e. The performance of rock-filled gabions as a base course over a soft subgrade.
- f. The benefits derived by tack-welding M8Al mat runners underneath an M8Al mat road placed on a soft subgrade.

17. Soil selected for construction of the soft subgrade was the heavy clay described in paragraph 7. At a moisture content of 35 to 40 percent, this soil can be compacted to obtain strengths of approximately 1.5 to 0.7 CBR. For this study a soft subgrade was defined as one having a strength of 1.5 CBR or less.

Construction

Subgrade

18. First, an area 210 ft long and 20 ft wide was excavated to a depth of approximately 24 in. below the existing ground. The walls and bottom of the excavation were lined with polyethylene to protect the subgrade from drying. The subgrade material, which had been processed to the desired moisture in a processing area, was placed and compacted in 6-in. lifts (Photo 1). The water content of the subgrade ranged from 35 to 37 percent. However, CBR test pits in the subgrade indicated higher CBR strengths than desired; the strengths generally increased with depth and ranged from 1.5 to 2.3 CBR. Therefore, the top 10 in. of subgrade was re-processed in place using a pulvimixer. The water content of this material

was increased to 38 to 40 percent, and the soil was recompactd using a D-4 tractor with street plates. Airfield penetrometer measurements indicated very uniform strengths for the top 10 in. of the subgrade. The CBR strengths for the reprocessed subgrade ranged from 0.7 to 1.0. These data are shown in Table 2 under zero traffic coverages.

Item 1 (M8A1 mat)

19. A section of T-16 membrane was placed over the subgrade of item 1 to keep the surface of the subgrade from drying. Next, two parallel runners of M8A1 mat were placed. The end connectors of the mat were used to join each panel to form a continuous runner of mat underneath each wheel path. M8A1 mat was then installed on top of, and perpendicular to, the parallel runners as shown in Photo 2. After each panel of the overlying mat was installed, the front edge was welded to each runner (Photo 3).

Item 2 (gabions and large size rock)

20. The gabions were preassembled and wired together according to manufacturer's instructions as shown in Photo 4. The gabions were then placed on the soft subgrade and filled with limestone rocks 3 to 7 in. in diameter as shown in Photo 5. The surface layer of rocks was arranged by hand to form a relatively smooth surface, and the lid of each gabion was wired shut. No attempt was made to compact the rocks in the gabions.

21. The 2-in. crushed-stone wearing surface was placed and compacted using a vibratory plate compactor. Some of the wearing surface material penetrated approximately 2 in. into the surface voids of the gabions.

Item 3 (fabric-lined gabions filled with sand)

22. The gabions used in item 3 were preassembled as in item 2. Each gabion compartment was then lined with polyester fabric as shown in Photo 6. The fabric-lined gabions were then placed on the subgrade and filled with sand as shown in Photo 7. The sand was compacted using a vibratory plate compactor, and then the gabion lids were wired shut sealing the sand in the gabion compartments. The 2-in. crushed-stone wearing surface was then placed and compacted as in item 2.

Item 4 (plastic tubes
filled with sand)

23. The 1-ft-long sections of plastic tubing used in this item were assembled and fastened together in a honeycomb arrangement as shown in Photo 8. This arrangement was then placed on the subgrade and filled with sand as shown in Photo 9. The vibratory plate compactor was used to vibrate the sand into and between the sections of tubing. The 2-in. crushed-stone wearing surface was then placed as in items 2 and 3.

Item 5 (crushed-stone base)

24. Item 5 was considered as a control item and was constructed by placing and compacting (using the vibratory plate compactor) three equal thickness lifts of the crushed-stone base material. Photo 10 shows this item as the first lift of material was being placed on the subgrade.

Item 6 (polyester fabric
under crushed-stone base)

25. This item was constructed identical with item 5 except that the polyester fabric was placed between the crushed-stone base and subgrade as shown in Photo 11.

Item 7 (T-16 membrane
under crushed-stone base)

26. This item was constructed identical with items 5 and 6 except that T-16 membrane was placed between the crushed-stone base and subgrade as shown in Photo 12.

Shoulders

27. Shoulders were constructed using materials and dimensions as described in paragraph 6. The completed test section with shoulders is shown in Photo 13.

PART III: TRAFFIC TESTS AND RESULTS

Application of Traffic

28. Test traffic was applied during January and February of 1976. Traffic was applied using the 5-ton, tandem-axle, military dump truck shown in Photo 14. The test section was trafficked as a one-lane road. The truck was driven in forward and then reverse over the entire length of the test section. Traffic was recorded in terms of coverages of equivalent 18-kip single-axle, dual-wheel load operations. The front single-axle, single wheels of the test vehicle did not contribute significantly to the test traffic;* therefore, only the rear tandem-axle, dual wheels were used in the computing of traffic coverages.

29. The operations per coverage factor for tandem-axle, dual wheels having a load range of 20-50 kips and normal wander of 37 in. is 1.03.** However, wander for the test traffic was less than that of normal truck traffic; therefore, the operations per coverage factor for the tandem-axle, dual-wheel test traffic was assumed equal to 1.00. The sequence of loading in which the test traffic was applied and the resulting coverages of equivalent 18-kip single-axle, dual-wheel load operations are presented in Table 1.

30. Normal tracking procedure was to allow test traffic to continue on an item until an 11-in. rut developed, at which point the differential on the truck would drag. The item would be considered failed at this time, and test data would be taken. The ruts in a failed item were lined with a runner of landing mat (Photo 33) to allow traffic to continue on unfailed items.

Behavior of Test Section Under Traffic

Tests and observations

31. Visual observations, photographs, and cross-section level readings were recorded at intervals throughout the traffic test period. At

* Based on Table 7 and Plate 9 of Reference 3.

** From Table 7 of Reference 3.

the conclusion of traffic, trenches were excavated across the traffic lane to determine the condition of the subgrade and test item materials. The performance of the test items and data obtained are presented in the following paragraphs.

Item 1 (M8A1 mat)

32. During the first 500 coverages of test traffic, the M8A1 mat item with runners tended to seat itself into the soft subgrade. Plate 3 shows a typical cross section showing the elevation of the mat surface before traffic and after seating at 500 coverages. Photo 15 shows the mat in excellent condition after 1000 coverages. The mat was very stable during traffic and did not shift or require any anchoring. After 15,000 coverages, the mat was still in excellent condition and showed no signs of damage.

33. Since it appeared that the mat would handle a large amount of additional traffic without damage, the mat runners were removed from half the item to compare the item performance with and without the runners. The portion of item 1 without runners was designated item 1A. Since initial traffic on item 1A caused substantial movement in both the mat and subgrade, lead weights were used to anchor the end of the mat on item 1A. After 39,100 coverages (Photo 16), item 1A was considered failed. One mat panel was broken and many of the bayonet side connectors had broken off. Plate 3 shows a typical cross section of the mat surface at zero and at 39,100 coverages. Approximately 2 to 3.5 in. of subgrade soil had been displaced under each wheel path.

34. The remaining portion of item 1 remained in excellent condition at the conclusion of traffic after 54,000 coverages (Photo 17 and Plate 3).

Item 2 (gabions with rocks)

35. This item performed quite well throughout the 54,000 coverages. Photos 18, 19, and 20 show this item after 100, 5500, and 54,000 coverages, respectively. Plate 4 shows typical cross-section data of the surface of the item at various coverage levels and also the contour of the bottoms of the gabions after 54,000 coverages. Slight upheaval of the gabions did occur at both edges of the item and also at the center line between the wheel paths.

36. A cross-section excavation of the item showed that no gabion wires were broken. The surface wearing course had filled the surface voids in the gabions to a depth of approximately 2 in. The subgrade material had entered from the bottom of the gabions and filled all remaining voids within the gabions.

Item 3 (fabric-lined gabions
filled with sand)

37. Performance of this large-compartment sand-confinement item was surprisingly good. A total of 11,500 coverages were applied before an 11-in. rut developed in the west wheel path. At 100 coverages (Photo 21) the item was in excellent condition and had an average rut of 2.2 in. At 5500 coverages (Photo 22), the average rut was 7.3 in. and signs of upheaval and shifting of sand within the compartments could be seen. Photo 23 shows the item after 11,500 coverages when 11 in. of rutting had finally developed in the west (foreground) wheel path. Typical cross-section data for this item are shown in Plate 5. The gabion wire and the polyester fabric were still in excellent condition at the conclusion of traffic.

Item 4 (plastic tubes
filled with sand)

38. This small-compartment sand-confinement item performed extremely well during the first 500 coverages. After 100 coverages (Photo 24), the average rut depth was 1.5 in. Visual observation showed this item to be very stable during the first 500 coverages. However, after 500 coverages, the tandem-axle load was increased from 25,000 to 35,000 lb, and the item performed significantly different with the new traffic load. Additional traffic caused a spot type failure to start to develop in the west wheel path. Photo 25 shows the item after 1000 coverages when the potential failure was noticed. Photo 26 shows the item after 2500 coverages when the average rut depth was slightly over 6 in. At this coverage level, the plastic tubing became visible as the spot failure continued to develop. After 5500 coverages (Photo 27), an 11-in. rut had developed at one spot, and the differential of the truck began to lift the plastic tubes from the item. It should be noted in Photo 27 that although half the item had developed an 11-in. rut, the remaining portion had an average rut of

only approximately 6 in. Typical cross-section data are shown in Plate 6. Photo 28 shows a typical cross-section view after the wearing surface was removed after 5500 coverages. The individual sand-filled plastic tubes along each wheel path had been pushed into the subgrade. This caused the subgrade to upheave between the wheel paths and along the outer edge of each wheel path.

39. The west shoulder along this item was 4 ft wide at the surface while the east shoulder was 3 ft wide at the surface. It should be noted that the 3-ft-wide sand shoulder was not strong enough to confine the 1-ft-long vertical sections of plastic tubing. The plastic tubes along the outer east wheel path tended to shift outward a few inches during traffic; however, the 4-ft shoulder on the west side did not permit the tubes to shift laterally during the traffic period.

Item 5 (control)

40. Performance of the control item was slightly better than predicted. After 100 coverages (Photo 29), the average rut depth was 4.5 in. By 200 coverages (Photo 30) an 11-in. rut had developed. Plate 7 shows typical cross-section data for this item during traffic. A trench excavated across the item showed that the crushed-stone base had penetrated approximately 3 in. into the subgrade. The trench also showed that the subgrade material had migrated 10 in. upward into the base near the center line between the wheel paths. This subgrade material had migrated from the west wheel path, indicating that the subgrade was slightly weaker on this side.

41. Failure of this item probably resulted as follows. The first coverages of traffic resulted in an intermixing of the base and subgrade materials until the subgrade had penetrated approximately 3 in. into the bottom of the base. Additional traffic caused some slight rutting in the subgrade which caused the subgrade material to migrate outward and upward on both sides of the wheel path. This outward and upward migration of the subgrade caused some upheaval in the base layer--most pronounced at the inner edge of the west wheel path. This, in turn, caused a shearing action near the bottom of the base, and the base material began to move laterally and upward--most pronounced at the inner edge of the west wheel

path. Additional traffic accelerated the base movement, causing additional rutting.

Item 6 (polyester fabric
under crushed-stone base)

42. Performance of this item was significantly better than that of the control item. After 100 coverages (Photo 31), the average rut depth was 1.8 in. After 200 coverages (Photo 32), the average rut depth was only 2.6 in. Photo 32 shows some transitional rutting resulting from failure of the control item and also some spot rutting at two locations. A test hole was dug into the larger spot rut to see if the polyester fabric had been damaged. The fabric was found to be in good condition but did show some signs of stretching.

43. After 2500 coverages (Photo 33), an 11-in. rut had developed in the west wheel path. The rutting was less in the east wheel path. Plate 8 shows cross-section data where the test trench was excavated in this item. The polyester fabric had absorbed a lot of clay particles and had stretched to the configuration shown in Plate 8. The fabric did not tear and was successful in separating the base and subgrade during traffic.

44. Failure of this item was caused by rutting and upheaval of the subgrade. This caused the base to shear and move outward and up.

Item 7 (T-16 membrane
under crushed-stone base)

45. Performance of this item was outstanding. Photo 34 shows this item after 5500 coverages. Average rut depth was only 1.8 in. An 11-in. rut did not develop until 37,000 coverages. Traffic on this item was continued to 54,000 coverages (Photo 35) to see if the T-16 membrane would tear. However, after 54,000 coverages, the membrane was still in good condition. Plate 9 shows cross-section data for this item. It is interesting to note that failure was caused by subgrade rutting and was not accompanied by base flow from under the wheel paths.

46. The base remained 14 in. thick except where it was stretched to conform with the subgrade or where it was disturbed by the differential on the truck. Plate 10 shows how the membrane was deformed during traffic.

The membrane was stretched 6 in. to conform with the subgrade, but it did not tear or pull in from the sides.

Summary of Test Results

After-traffic subgrade tests

47. Water content, density, and CBR data taken from within the remaining portion of the top 10 in. of subgrade are shown in Table 2. In general, the data were taken in the west rut. However, in items 6 and 7 data were also taken from the east rut in an attempt to explain the difference in performance that occurred between the east and west traffic wheel paths in these two items.

48. The rated subgrade CBR values shown in Table 2 are based on the numerical average of the CBR values measured immediately after construction (zero coverages) and after traffic. The rated CBR is based only on the top 10 in. of subgrade material that was reprocessed during construction.

Coverages versus rut depth

49. Plates 11 and 12 show plots of coverages versus rut depth for test items 2 through 7. These plots were developed from cross-section measurements taken in the west wheel path of each test item. The data points shown represent the average rut depth calculated from three cross sections per test item at each indicated coverage level.

PART IV: ANALYSIS

Design Criteria Versus Control Item 5

50. A mathematical expression for determining the required thickness of cover material for unsurfaced roads and airfields was developed and presented in Reference 4. The equation is as follows:

$$t = (0.176 \log C + 0.120) \sqrt{\frac{P}{8.1(\text{CBR})} - \frac{A}{\pi}}$$

where

t = design thickness, in.

C = coverages

P = single or equivalent single-wheel load, lb

A = tire contact area, sq in.

Using this equation and the results of this investigation, a comparison of design estimated coverages and actual coverages was made. First, the design estimated coverages for the control item 5 were calculated as follows:

$$t = (0.176 \log C + 0.120) \sqrt{\frac{P}{8.1(\text{CBR})} - \frac{A}{\pi}}$$

where

t = 14 in.

P = 47 percent* (18,000 lb) = 8460 lb

A = 85 sq in.**

Rated CBR = 0.9

C = design estimated coverages for 3-in. rut

* Equivalent single-wheel load in percent of axle load versus depth obtained from single-axle, dual-wheel curve in Plate 7 of Reference 3.
** Tire contact area for one wheel of 18,000-lb single-axle, dual-wheel loading.

Therefore, for control item 5:

$$14 = (0.176 \log C + 0.120) \sqrt{\frac{8460}{8.1(0.9)} - \frac{85}{\pi}}$$

$$C = 48$$

This indicates that after 48 coverages the control item should have about a 3-in. rut. From Plate 12 the actual rut depth after 48 coverages was 2.4 in, and a 3.0-in. rut depth occurred at 68 coverages. Thus, the equation predicted with reasonable agreement what the performance of the control item would be.

Test Section Performance

51. The thickness equation was then plotted in terms of coverages versus design thickness for an 18,000-lb single-axle, dual-wheel load. The results are shown in Plate 13 using subgrade CBR's of 0.9, 1.0, and 1.1 (rated subgrade CBR's for west wheel paths of items 2 through 7). Plate 7 of Reference 3 was used in computing the equivalent single-wheel load for the 18,000-lb single-axle, dual-wheel load.

52. Using the actual traffic coverage data from the test section (Plates 11 and 12), a performance thickness in in. was determined for test items 2 through 7 using the CBR design plots shown in Plate 13. A performance thickness was determined using coverage data obtained at 3-, 6-, and 11-in. rut depths. These data were plotted as shown in Plate 14. The CBR design criteria for the 3-in. rutting failure criteria were also plotted and extrapolated for the 6- and 11-in. rutting failure criteria using the performance of the control item 5 as a guide. This extrapolation was necessary since no mathematical expression of CBR design relations presently exists for the 6- and 11-in. rutting failure criteria.

53. It should be noted that the 3-in. rut design criteria were developed based on the results of 59 test items (Reference 4). The subgrade cover material for 39 of the 59 test items had a strength of ≤ 20 CBR. The subgrade cover material for control item 5 for this test section

was approximately 100 CBR. This could explain the slightly better performance of item 5 when compared with the present design criteria.

Design Thickness Savings

54. From the analysis presented in Plate 14, design thickness savings were calculated for each item. For example, based on the 3-in. rutting failure criteria, the performance of item 7 was equivalent to a 29-in.-thick pavement instead of its actual thickness of 14 in. Therefore, a design thickness savings of 15 in. resulted (29 in. minus 14 in.). This represents a design thickness savings of 52 percent (15 in. divided by 29 in. times 100 percent). Based on the 6-in. rutting failure criteria, the performance of item 7 was equivalent to a 31.4-in.-thick pavement instead of the extrapolated design performance thickness of 16 in. Therefore, a design thickness savings of 15.4 in. (31.4 in. minus 16 in.) or 49 percent resulted. Table 3 shows the design thickness savings in percent for test items 2 through 7 using 3-, 6-, and 11-in. rutting failure criteria. It should be noted that the data presented in Table 3 may be applicable only for soft subgrades having a strength of approximately 1 CBR. Additional tests would be necessary to relate design thickness savings to higher strength subgrades.

PART V: CONCLUSIONS

55. Based on this investigation, the following conclusions are believed warranted:

- a. The performance under traffic of a crushed-stone base placed directly on a soft subgrade can be predicted using the following equation:

$$t = (0.176 \log C + 0.120) \sqrt{\frac{P}{8.1(\text{CBR})} - \frac{A}{\pi}}$$

- b. An M8A1 mat road that is placed on and tack welded to parallel mat runners placed along the wheel paths can be used as a very effective bridge approach road over soft ground. The runners tend to effectively anchor the road so an additional anchoring system should not be required. Construction of the mat road could be performed during adverse weather conditions.
- c. The performance of rock-filled gabions as a base course for approach roads over soft ground is extremely good. The rock-filled gabions are free draining and would be ideal for low areas that have little or no drainage. Also, the gabions could be used for submerged approach roads if desired. The standard commercial gabions used in this investigation appeared to be overdesigned strengthwise and were time-consuming to install.
- d. The potential use of sand-confinement systems for base courses over soft subgrades is a major finding of this investigation. Both the large-volume confinement system (item 3) and the small-volume system (item 4) out-performed the crushed-stone control item by a substantial margin. A sand-confinement system could be developed that would provide an expedient construction technique for building approach roads over soft ground. The construction and performance of the sand-confined base system would not be adversely affected by wet weather conditions.
- e. The horizontal placement of fabrics or membranes between a soft clay subgrade and crushed-stone base can offer substantial savings in design thickness. These materials are light-weight and thus would be ideal for theater-of-operations use. They act as separators by keeping the subgrade material from entering and thus weakening the bottom portion of the base. They also offer tensile reinforcement at the interface between the base and subgrade. This serves to reduce the amount of rutting that occurs in the subgrade. Two fabric or membrane properties that are closely related to field performance are breaking strength and elongation.

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1. U. S. Department of Defense, "Military Standard for Unified Soil Classification System for Roads, Airfields, Embankments, and Foundations," MIL-STD-619B, Jun 1968, U. S. Government Printing Office, Washington, D. C.
2. U. S. Department of the Army Technical Manual, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations," TM 5-330, Sep 1968, Washington, D. C.
3. U. S. Army Engineer Waterways Experiment Station, CE, "Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations," Technical Report No. 3-582, Aug 1961, Vicksburg, Miss.
4. Hammitt, G. M., "Thickness Requirements for Unsurfaced Roads and Airfields, Bare Base Support, Project 3782-65," Technical Report S-70-5, Jul 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

Tandem-Axle, Dual-Wheel Test Traffic

<u>No. of Passes</u>	<u>Load lb</u>	<u>Equivalent 18-kip, Single-axle, Dual Wheel Coverages per Pass*</u>	<u>No. Coverages</u>	<u>Cumulative Coverages</u>
500	25,000	1	500	500
400	35,000	5	2,000	2,500
300	47,000	30	9,000	11,500
500	55,000	85	42,500	54,000

* From Plate 9 of Reference 3.

Table 2

Summary of Subgrade CBR, Water Content, and Density Data

Test Item	Station	Location	Traffic Coverages	Depth in.	CBR	Water Content %	Dry Density pcf	Rated CBR
1	--	General	0	0-10	0.7*	39.7	78.0	1.0
	0+22.5	West runner	54,000	0	1.2	39.2	77.9	
				6	1.3	38.8	77.7	
2	--	General	0	0-10	0.7	38.8	78.3	0.9
	0+45	West rut	54,000	0	1.0	40.3	78.1	
3	--	General	0	0-10	0.7	38.8	78.3	0.9
	0+75	West rut	11,500	0	1.2	39.8	77.9	
				6	1.1	40.5	77.8	
4	--	General	0	0-10	0.9	38.8	78.3	0.9
5	--	General	0	0-10	0.8	38.2	79.1	0.9
	1+35	West rut	200	3	1.2	38.4	78.4	
				8	0.9	37.6	80.8	
6	--	General	0	0-10	0.9	38.2	79.1	1.1
	1+57.5	West rut	2,500	0	1.3	37.2	79.9	
		West rut	2,500	6	1.2	38.8	79.1	
		East rut	2,500	0	1.2	38.1	78.8	
		East rut	2,500	6	1.7	36.6	80.5	
7	--	General	0	0-10	1.0	38.2	79.1	1.0
	1+87.5	West rut	54,000	0	0.9	39.2	78.9	
		East rut	54,000	0	1.5	37.5	79.5	

* The 0- to 10-in. CBR is based on surface CBR measurements and airfield penetrometer data.

Table 3

Design Thickness Savings

<u>Test Item</u>	<u>Design Thickness Savings, %</u> <u>Rutting Failure Criteria, in.</u>		
	<u>3</u>	<u>6</u>	<u>11</u>
2	44	53	58
3	30	41	48
4	40	41	40
5	8	8	6
6	18	20	27
7	52	49	48



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Photo 1. Installing soft clay subgrade on polyethylene

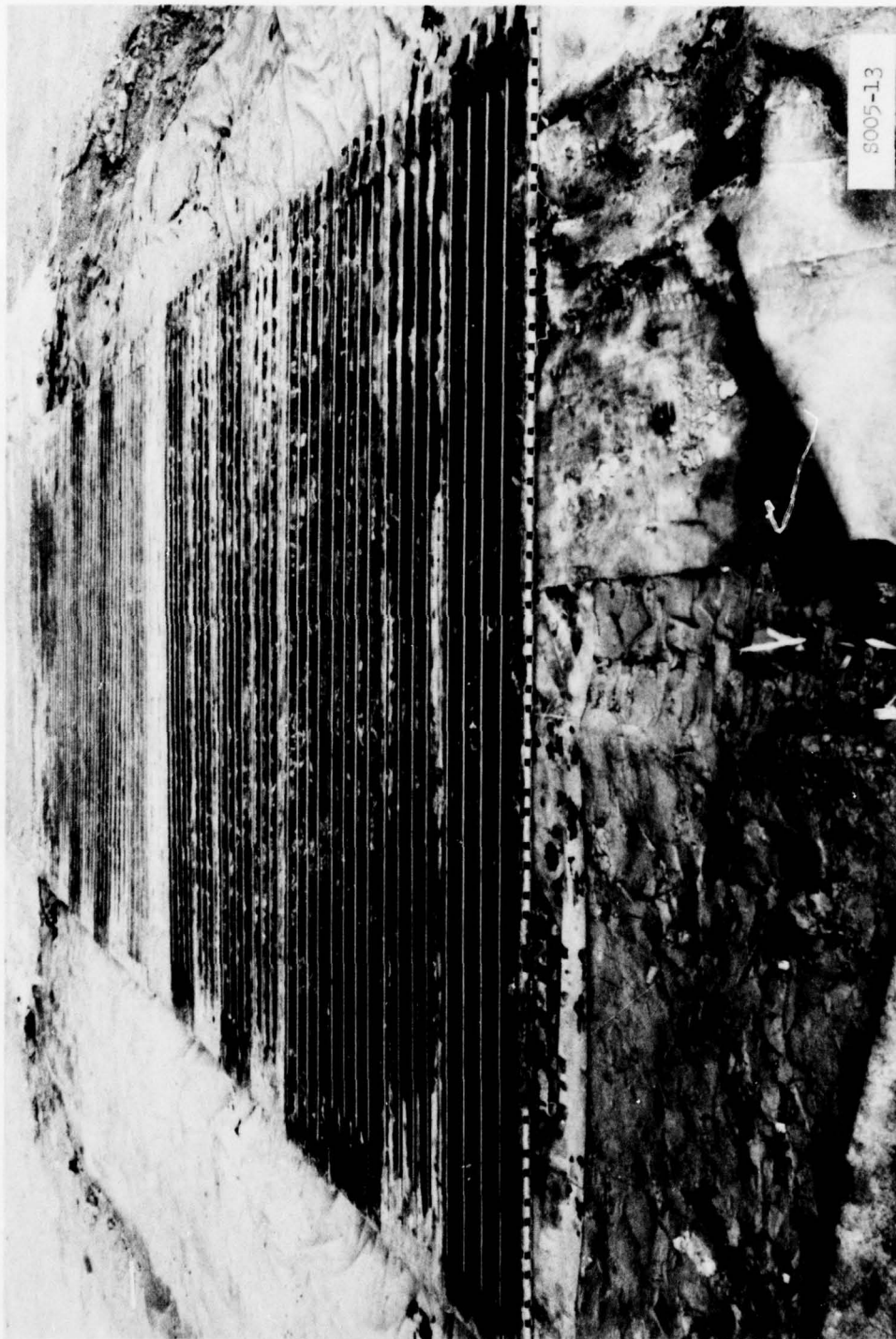


Photo 2. Item 1, M8A1 mat installed on runners

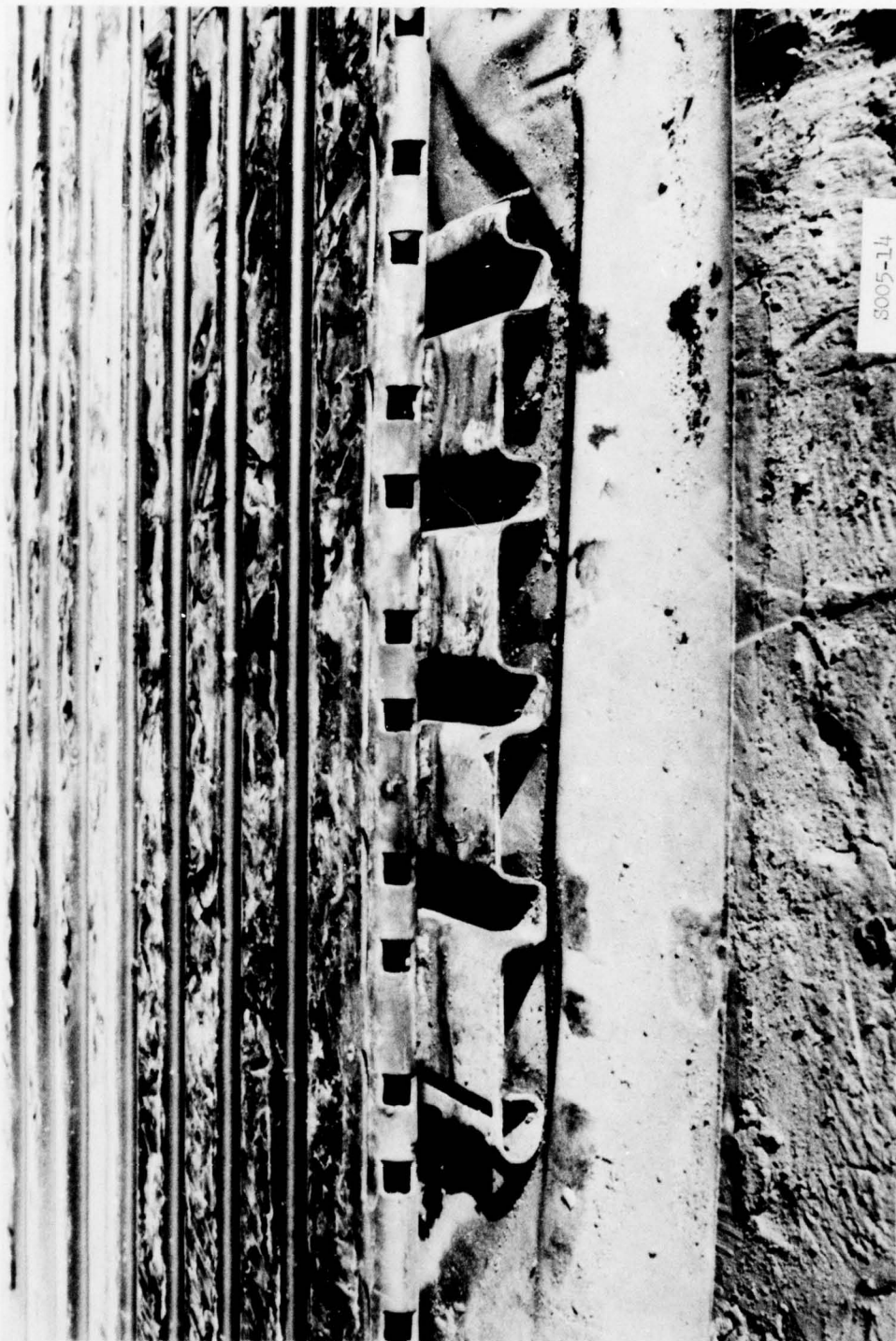


Photo 3. Item 1, close-up view of weld between front edge of mat panel and runner

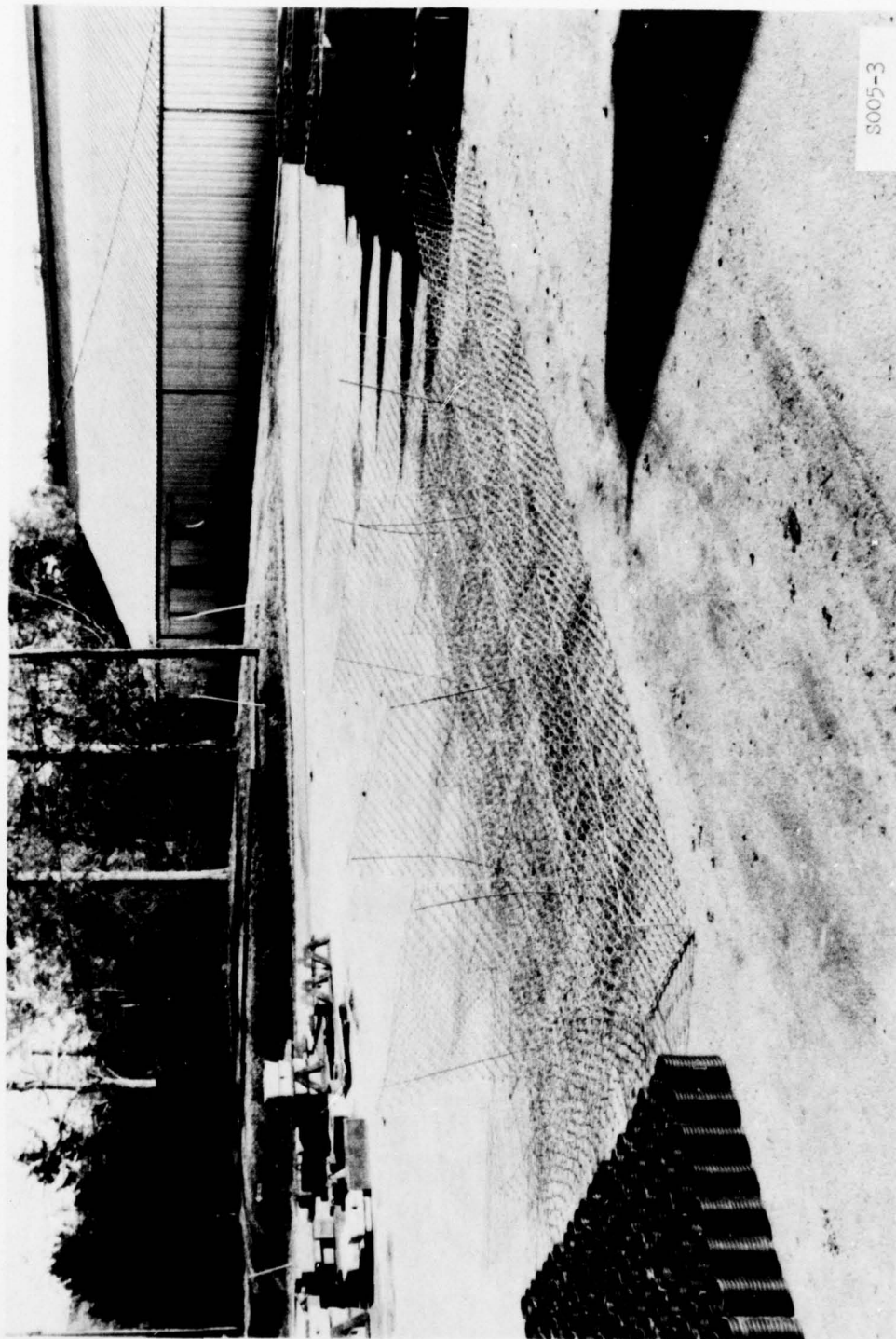
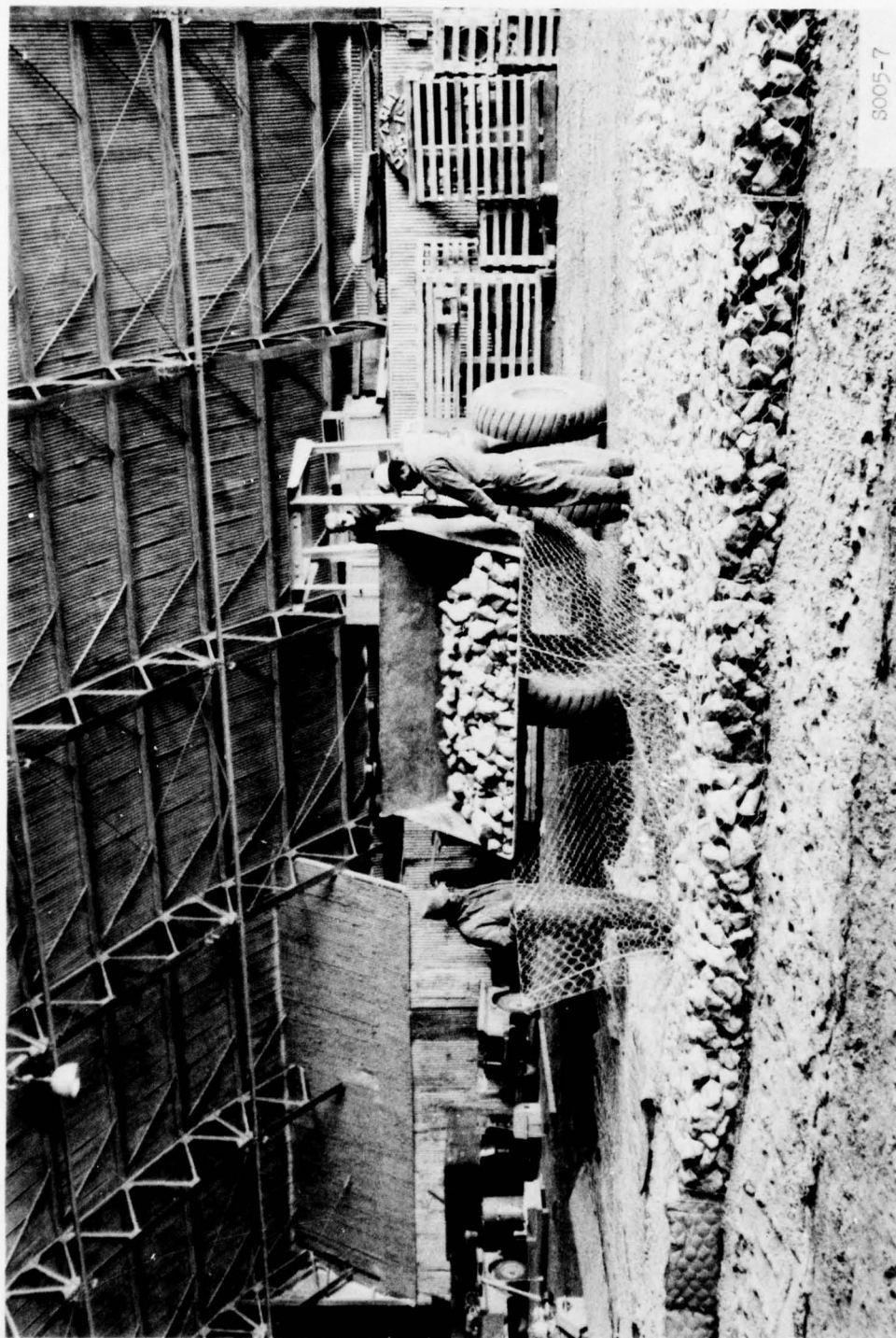


Photo 4. Assembled gabions for item 2



5005-7

Photo 5. Item 2, installing rocks in gabions



S005-4

Photo 6. Fabric-lined gabions for item 3



Photo 7. Item 3, installing and compacting sand in fabric-lined gabions

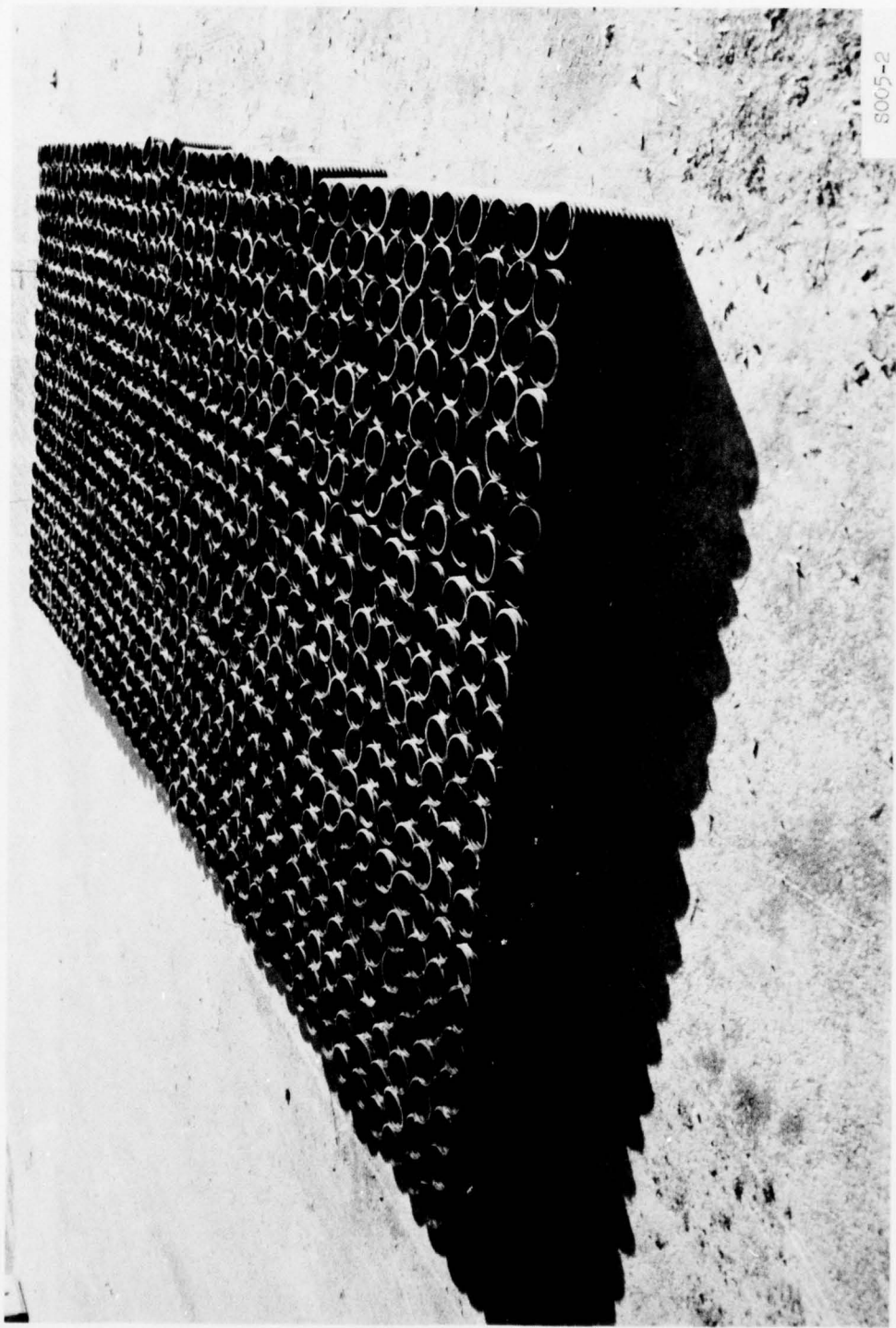


Photo 8. Honeycombed arrangement of plastic tubing for item 4

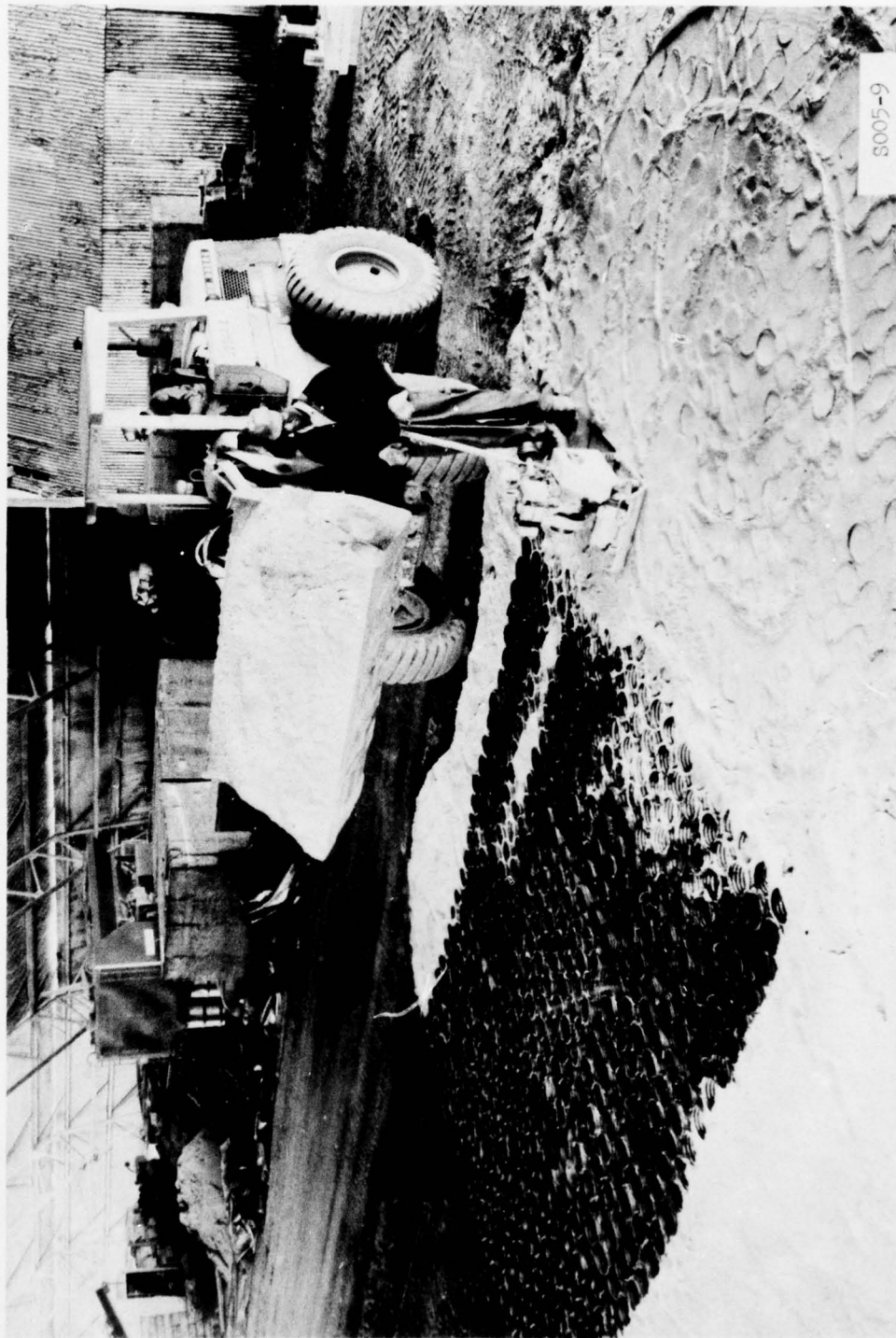
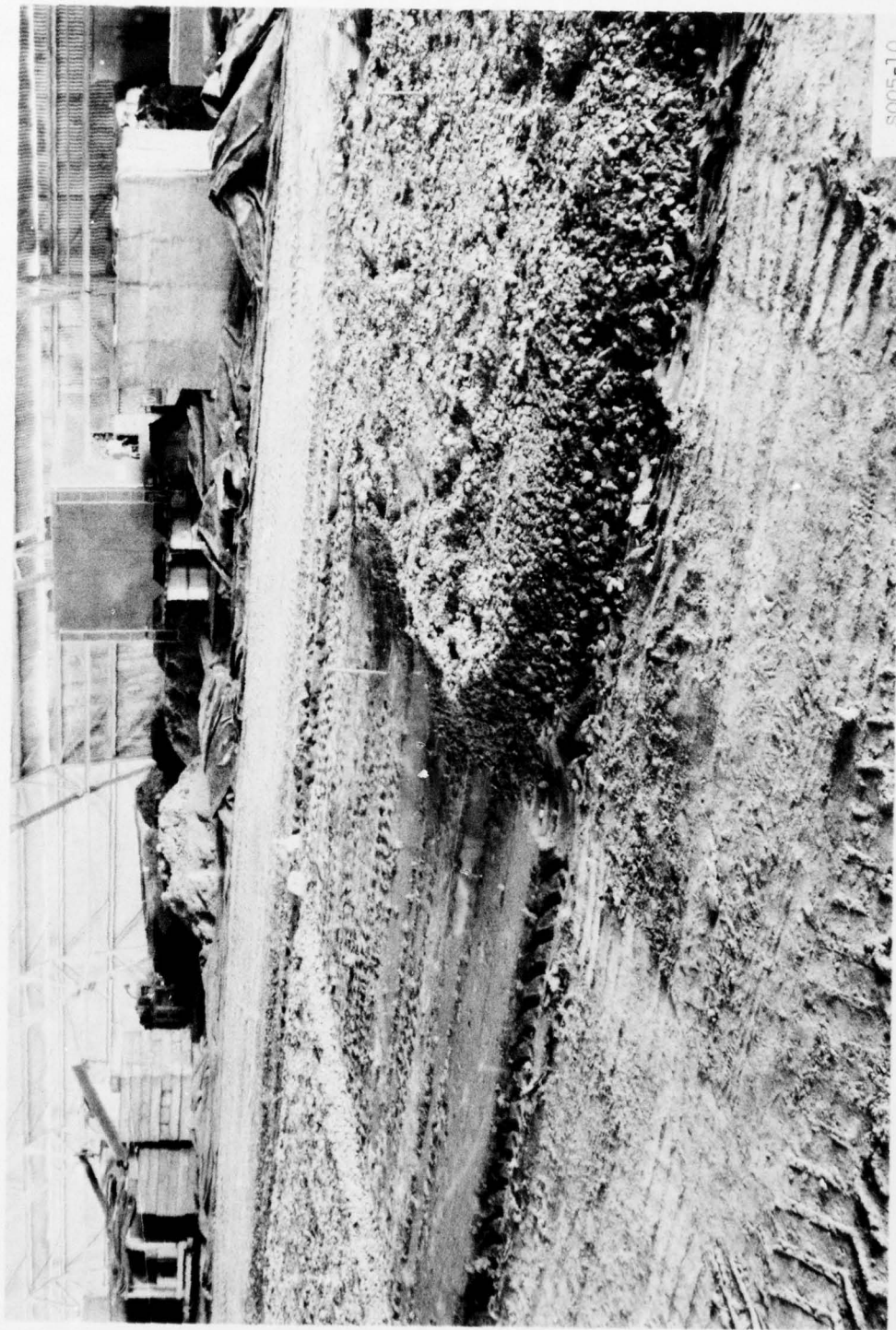


Photo 9. Item 4, installing and compacting sand in plastic tubing



S005-10

Photo 10. Item 5, crushed-stone base on soft subgrade

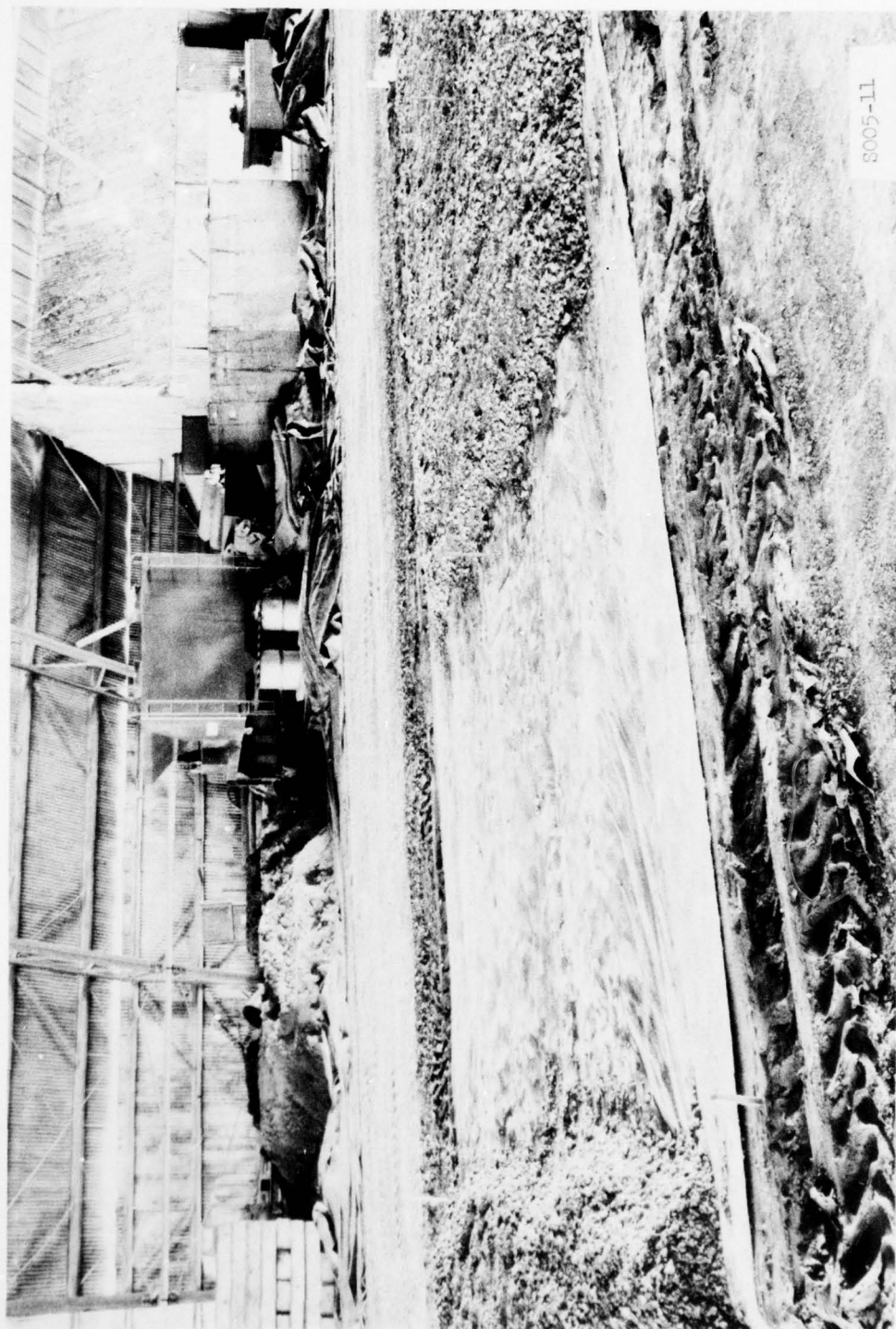


Photo 11. Item 6, crushed-stone base on polyester fabric



Photo 12. Item 7, crushed-stone base on T-16 membrane



8005-27

Photo 13. View of completed test section

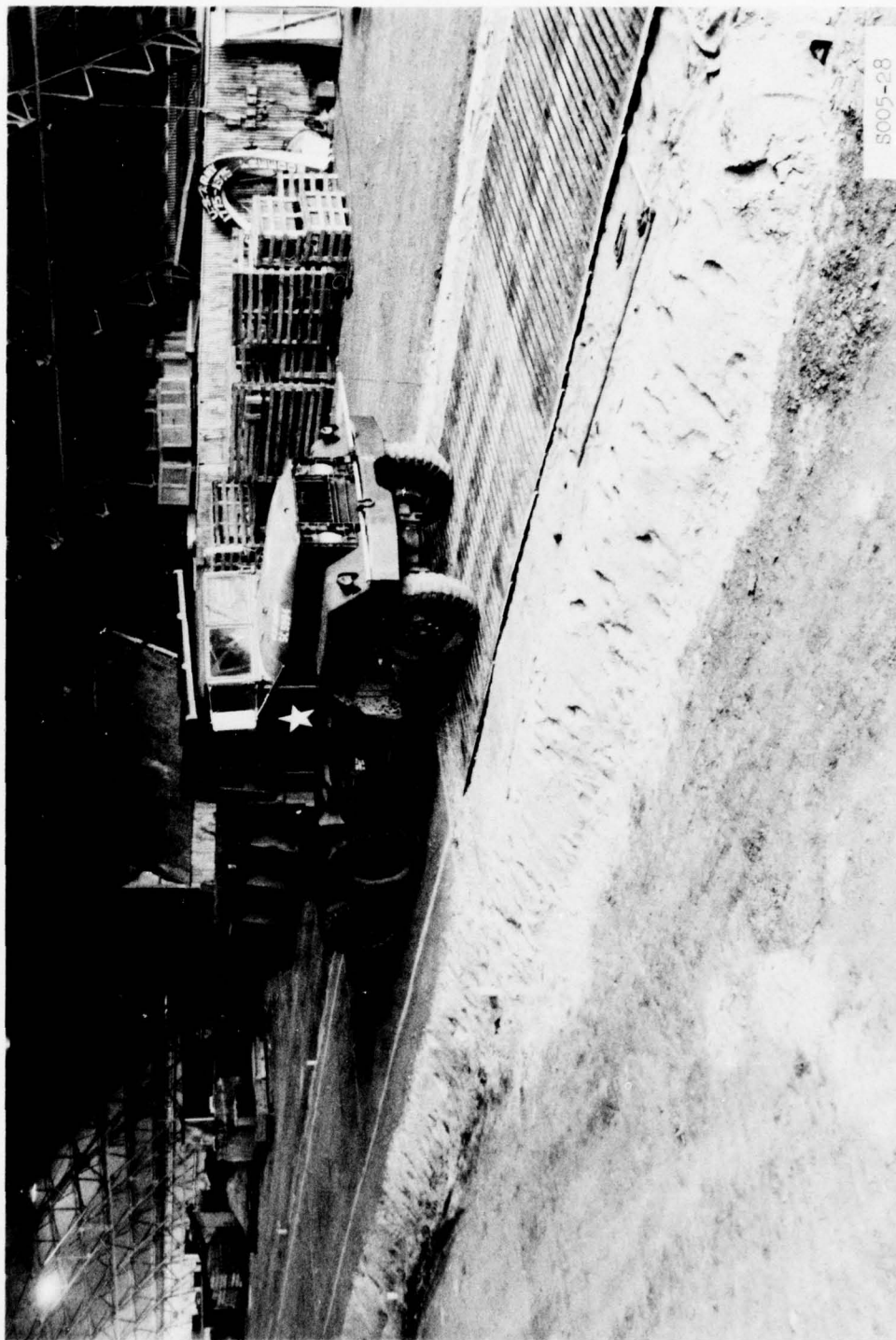


Photo 14. Vehicle used for traffic tests

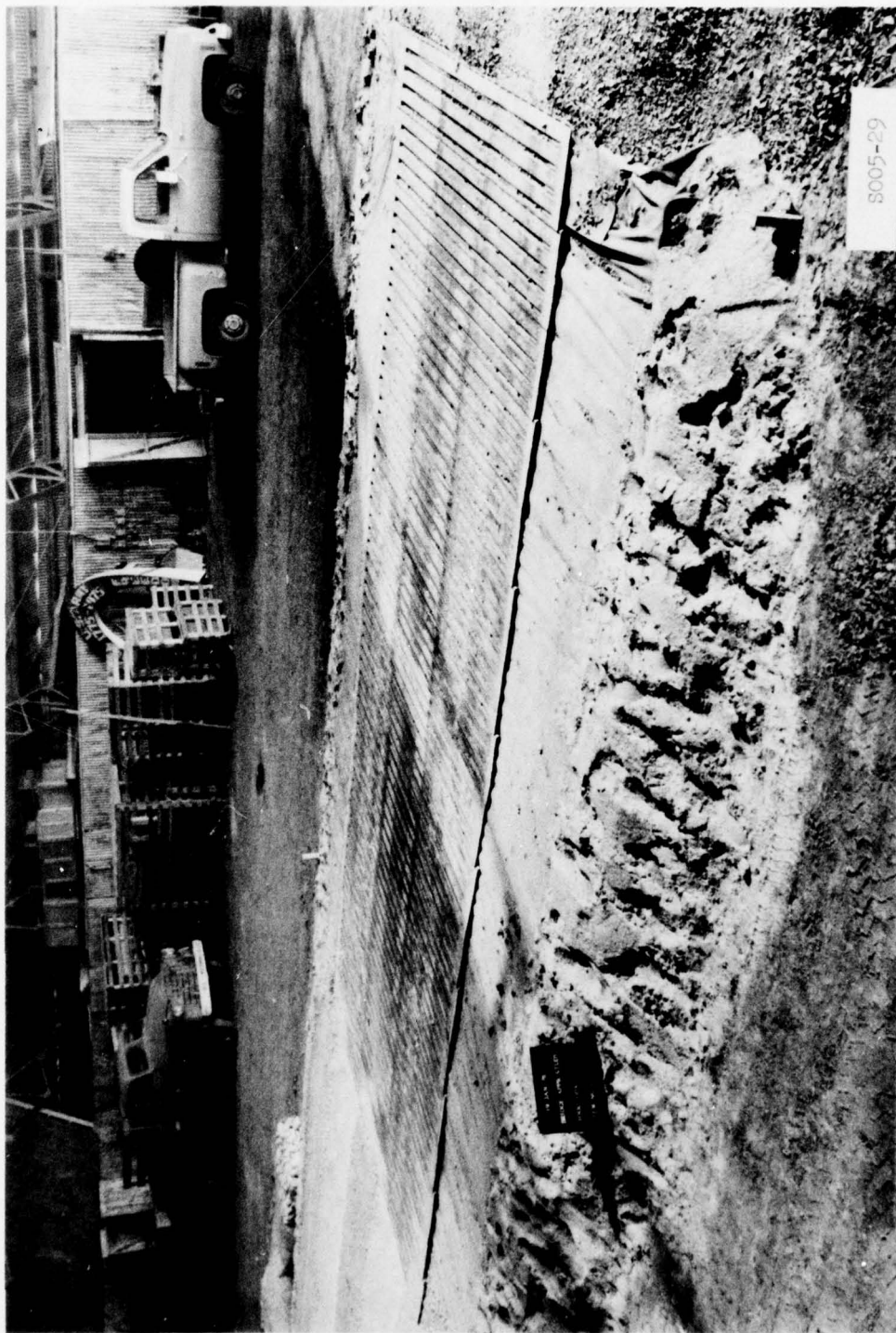


Photo 15. Item 1 after 1000 coverages



Photo 16. Item 1A after 39,100 coverages



Photo 17. Item 1 after 54,000 coverages



S005-23

Photo 18. Item 2 after 100 coverages



S005-41

Photo 19. Item 2 after 5500 coverages



Photo 20. Item 2 after 54,000 coverages

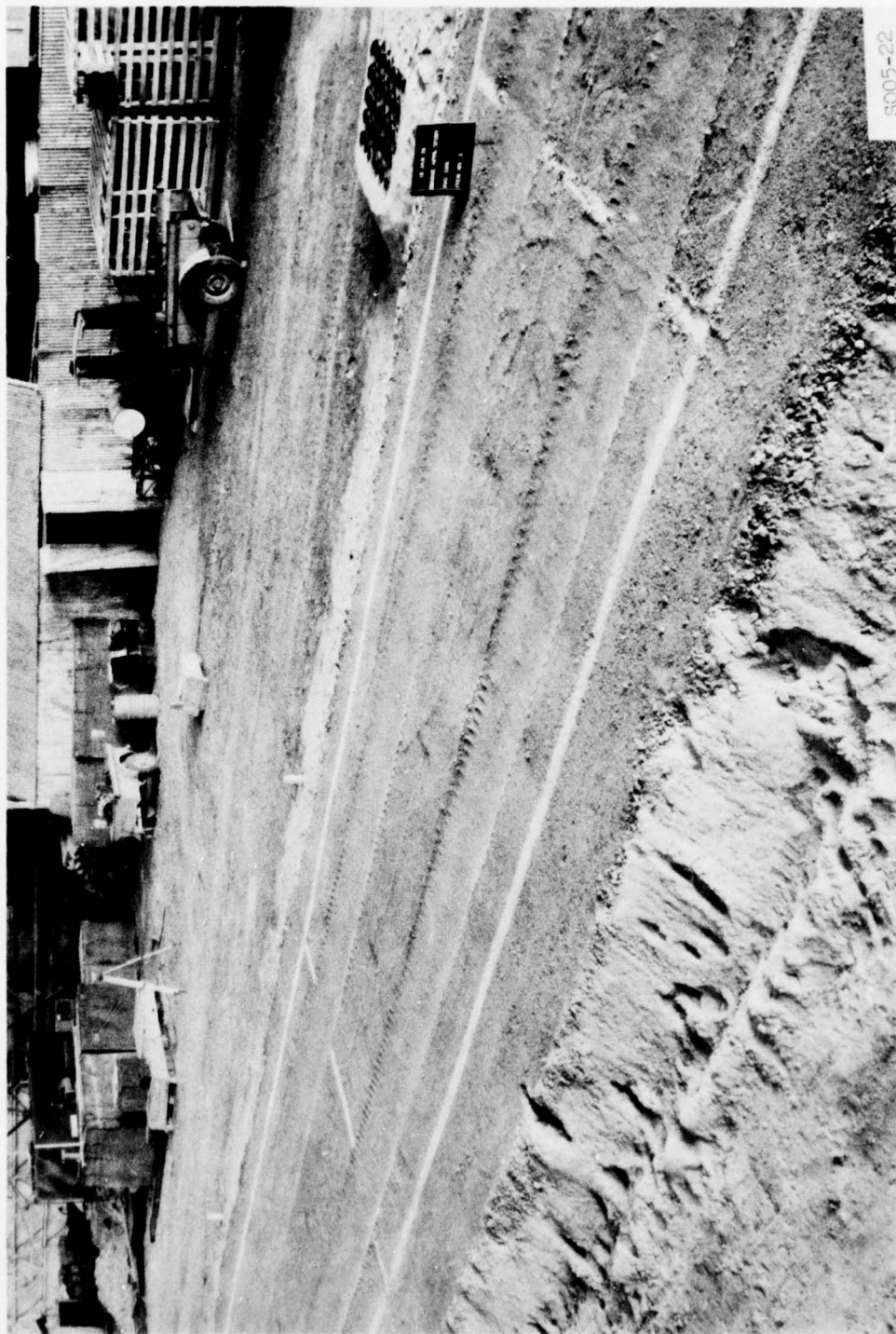


Photo 21. Item 3 after 100 coverages

S005-22

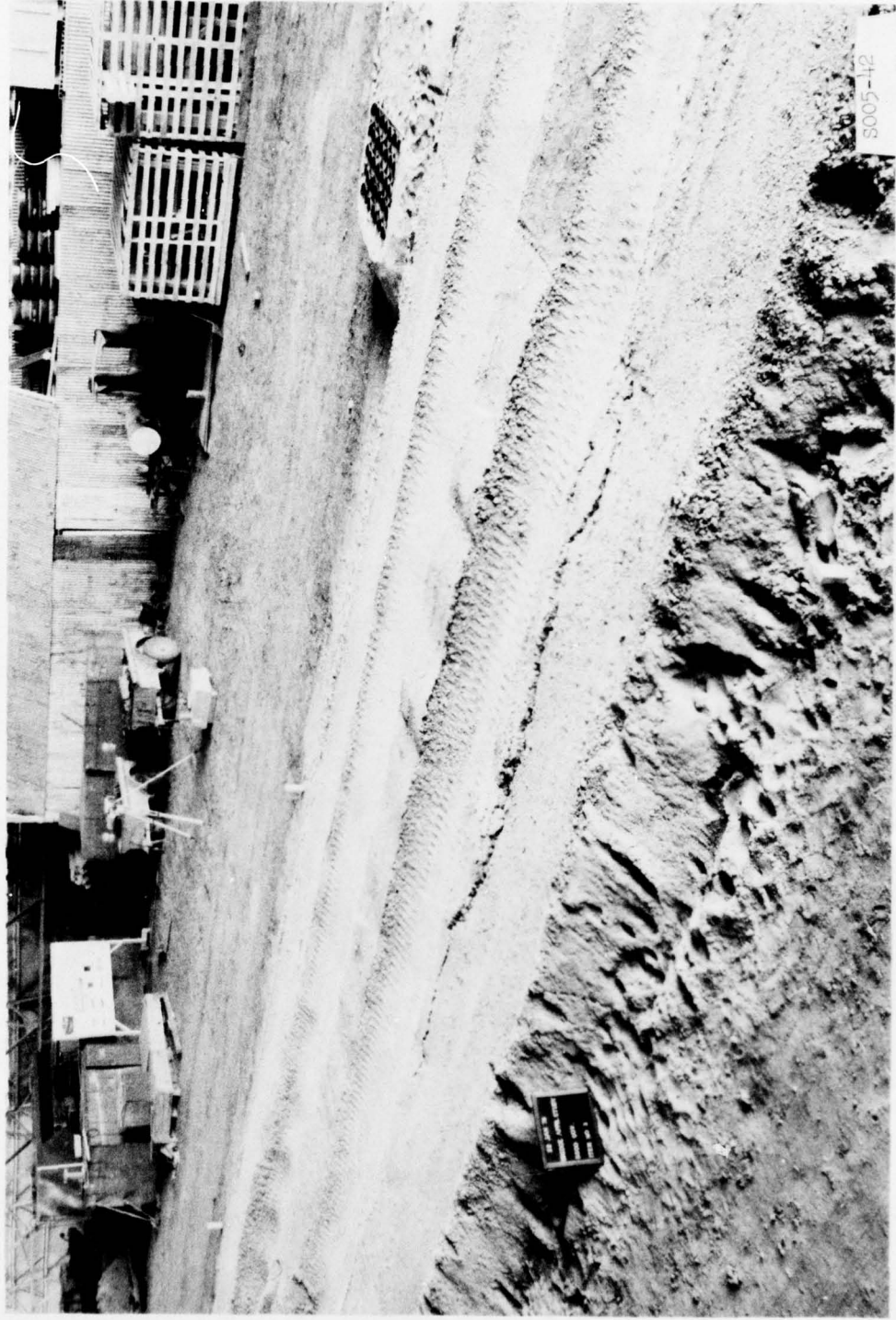


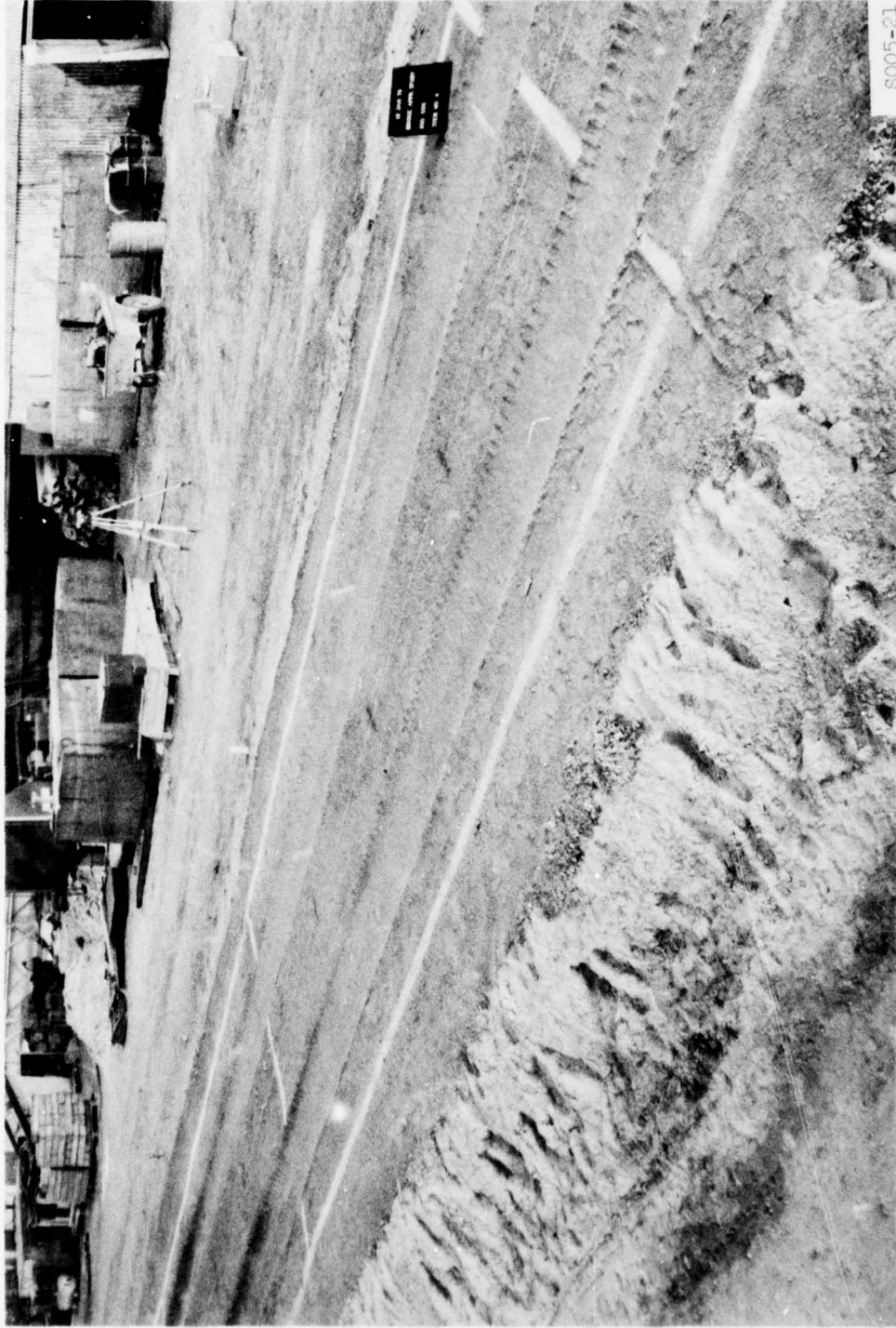
Photo 22. Item 3 after 5500 coverages

S005-412



S005-46

Photo 23. Item 3 after 11,500 coverages



S005-21

Photo 24. Item 4 after 100 coverages



Photo 25. Item 4 after 1000 coverages



Photo 27. Item 4 after 5500 coverages

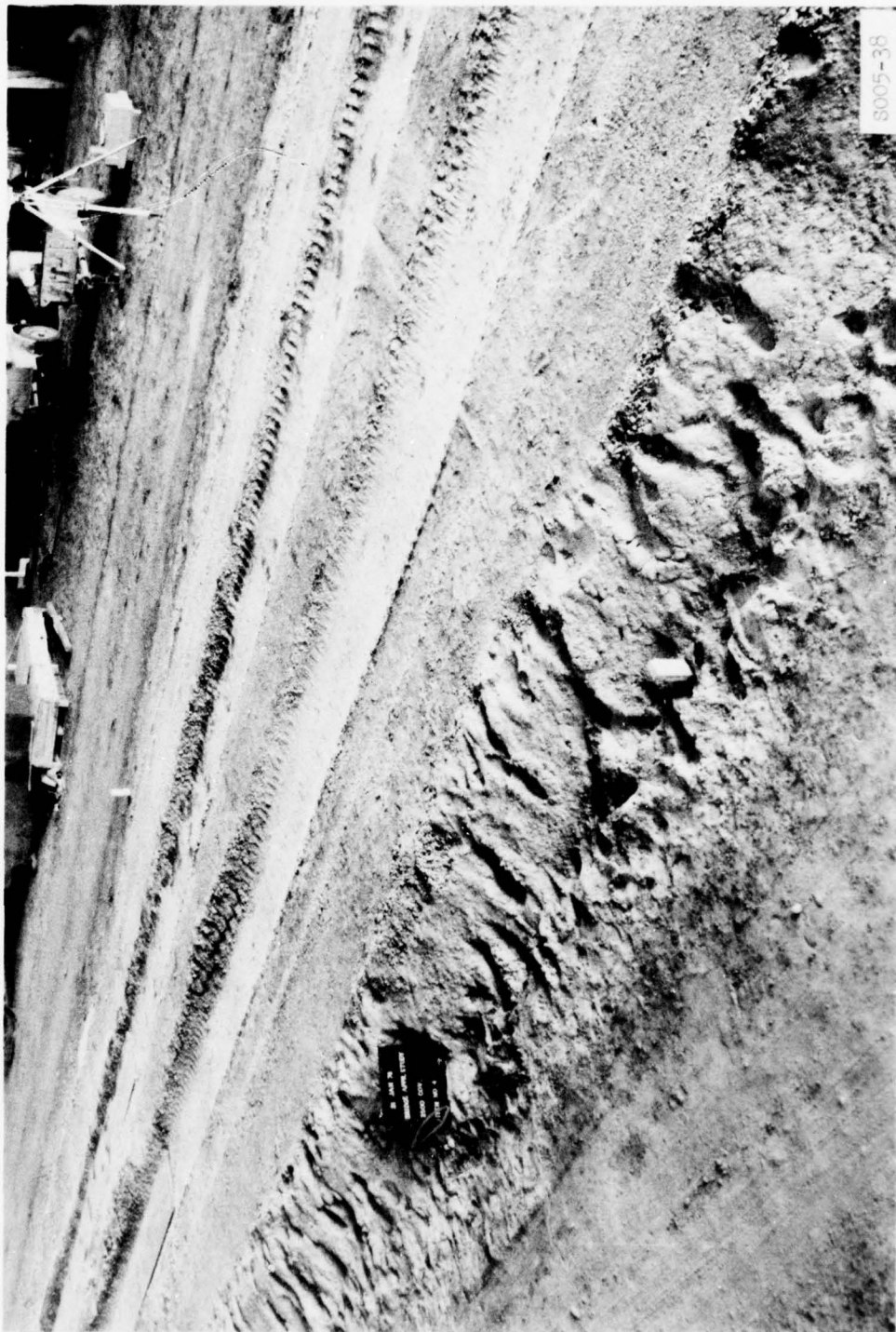


Photo 26. Item 4 after 2500 coverages

S005-38



Photo 27. Item 4 after 5500 coverages

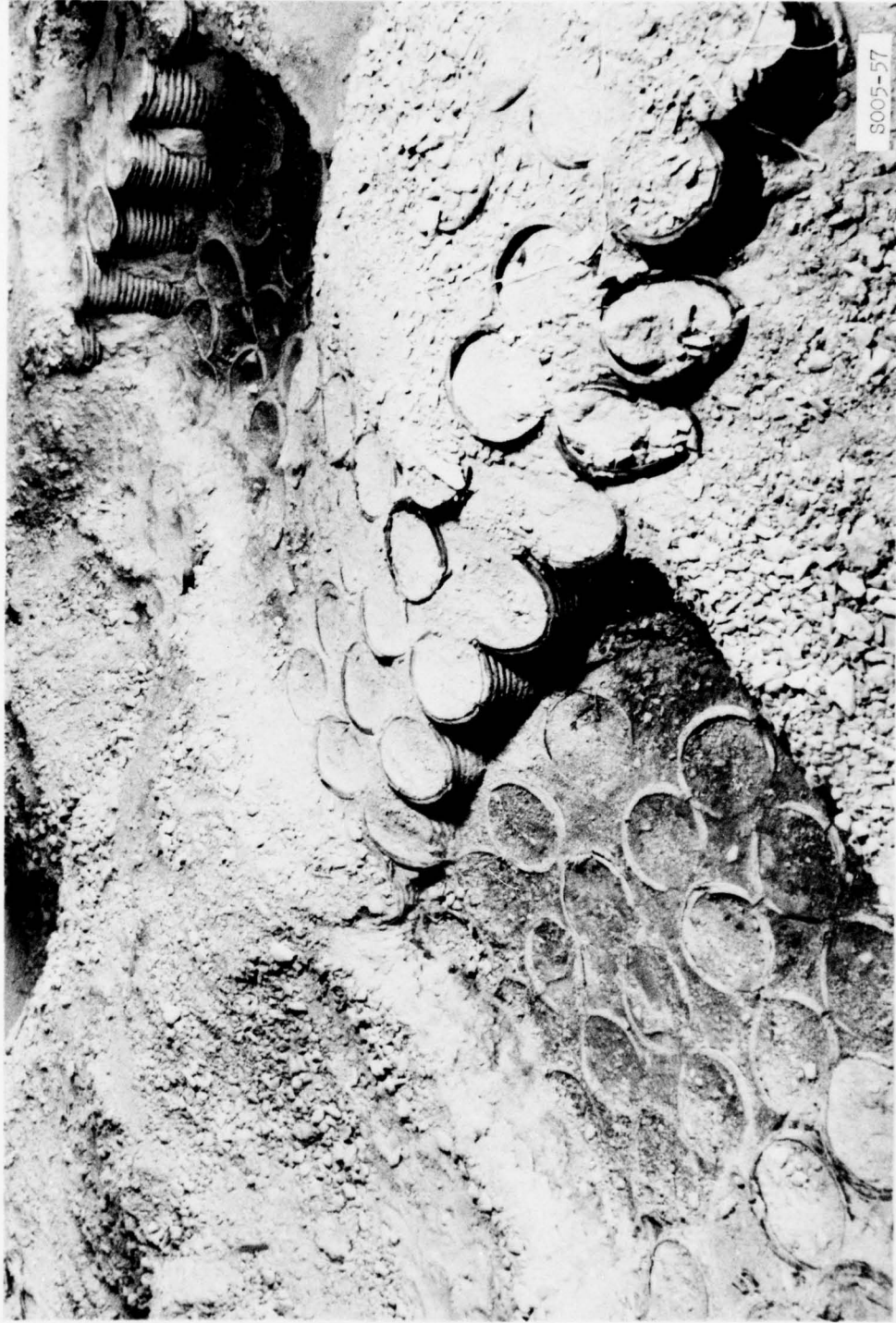
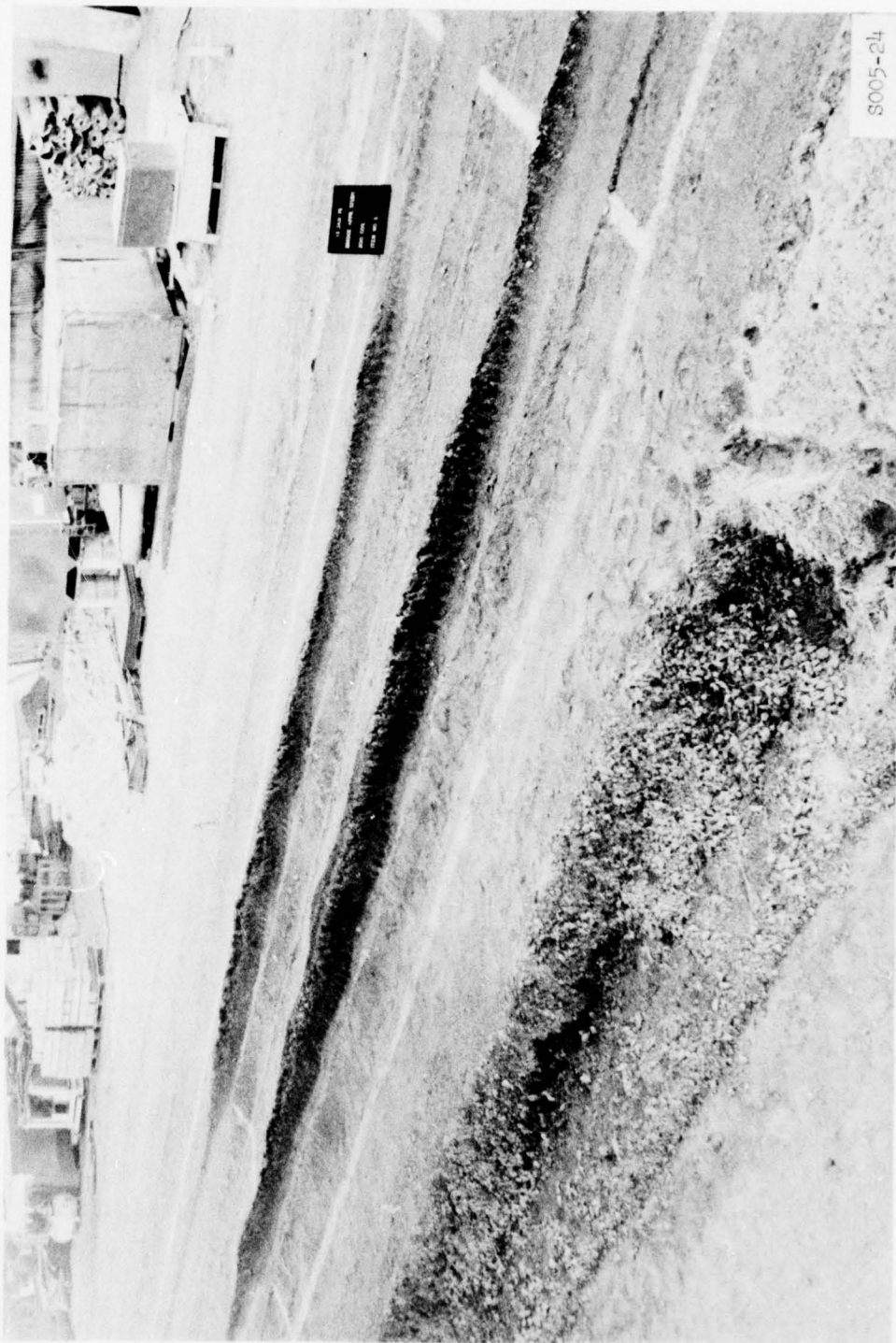


Photo 28. Item 4 with wearing surface removed after 5500 coverages



Photo 29. Item 5 after 100 coverages



S005-24

Photo 30. Item 5 after 2000 coverages



Photo 31. Item 6 after 1000 coverages

S005-19



Photo 32. Item 6 after 200 coverages



Photo 33. Item 6 after 2500 coverages



Photo 34. Item 7 after 5500 coverages

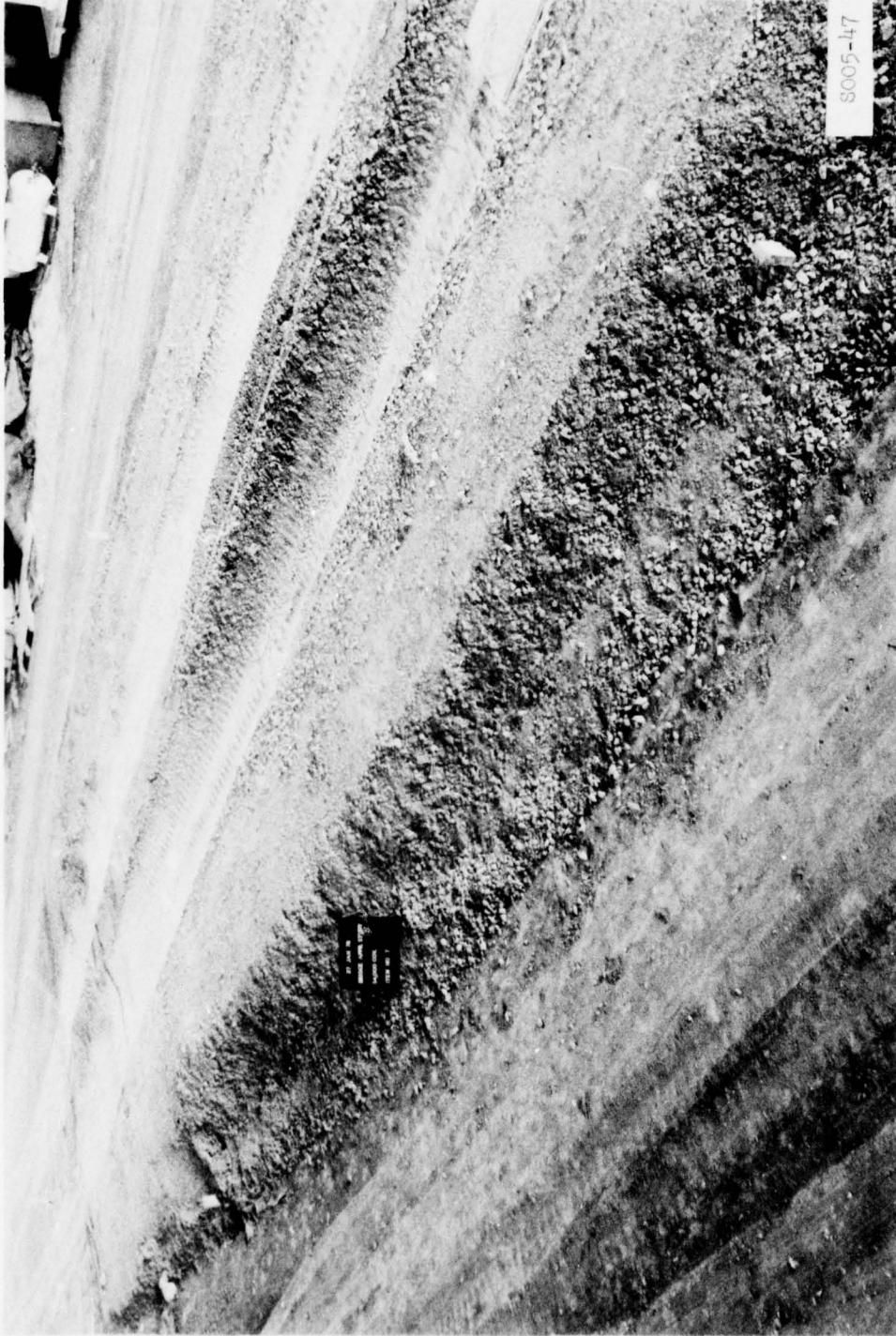
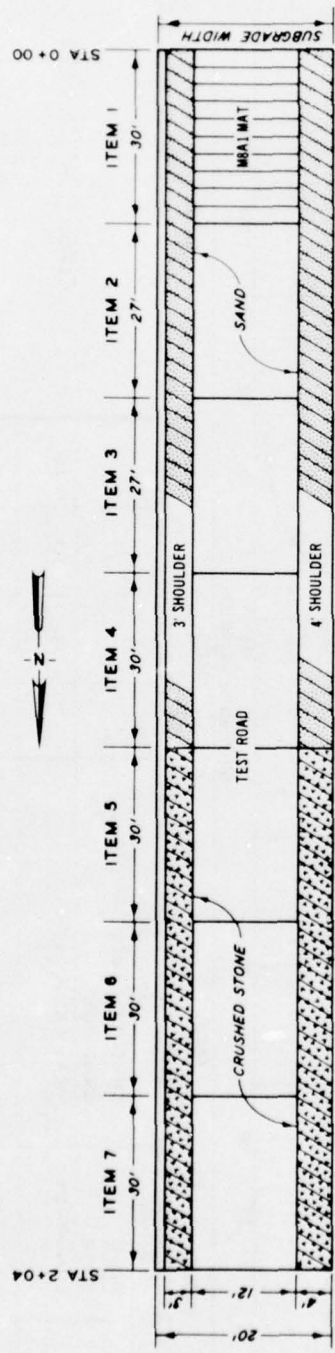
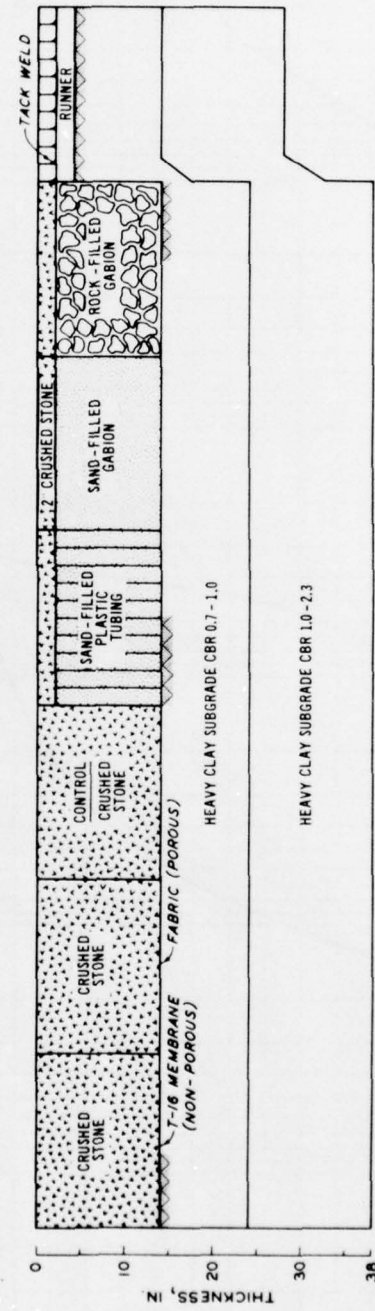


Photo 35. Item 7 after 54,000 coverages



PLAN



PROFILE

PLAN AND PROFILE

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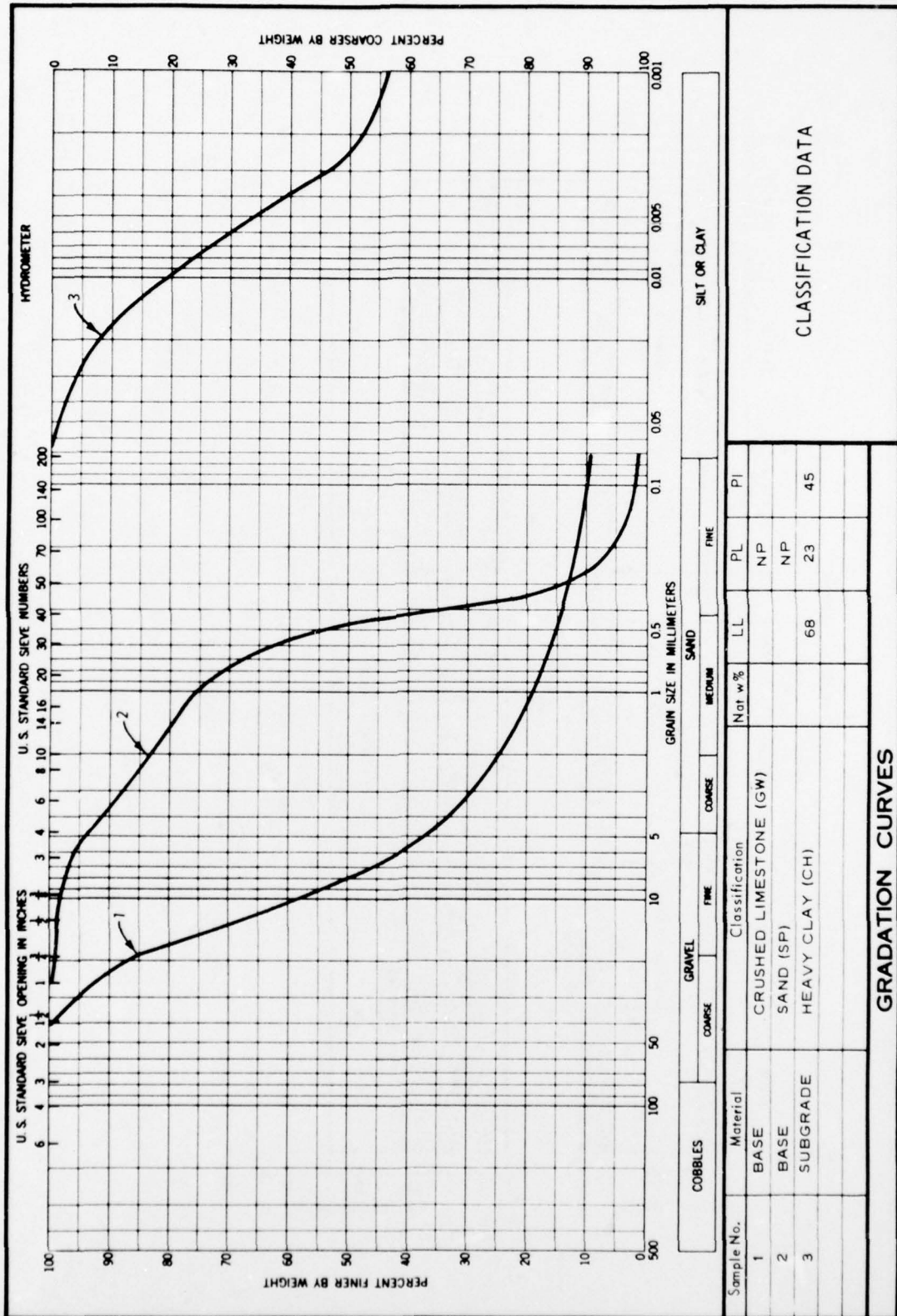
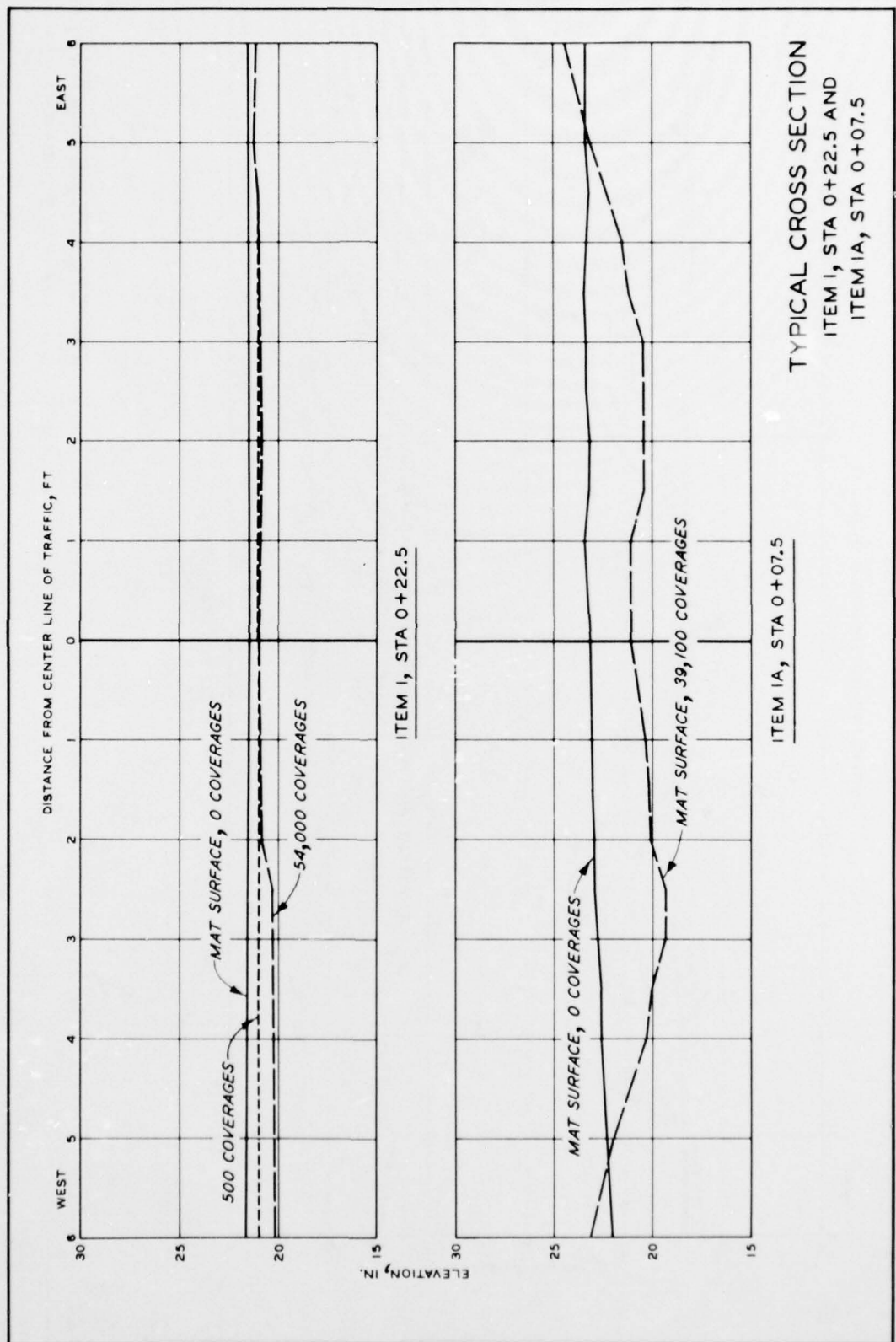
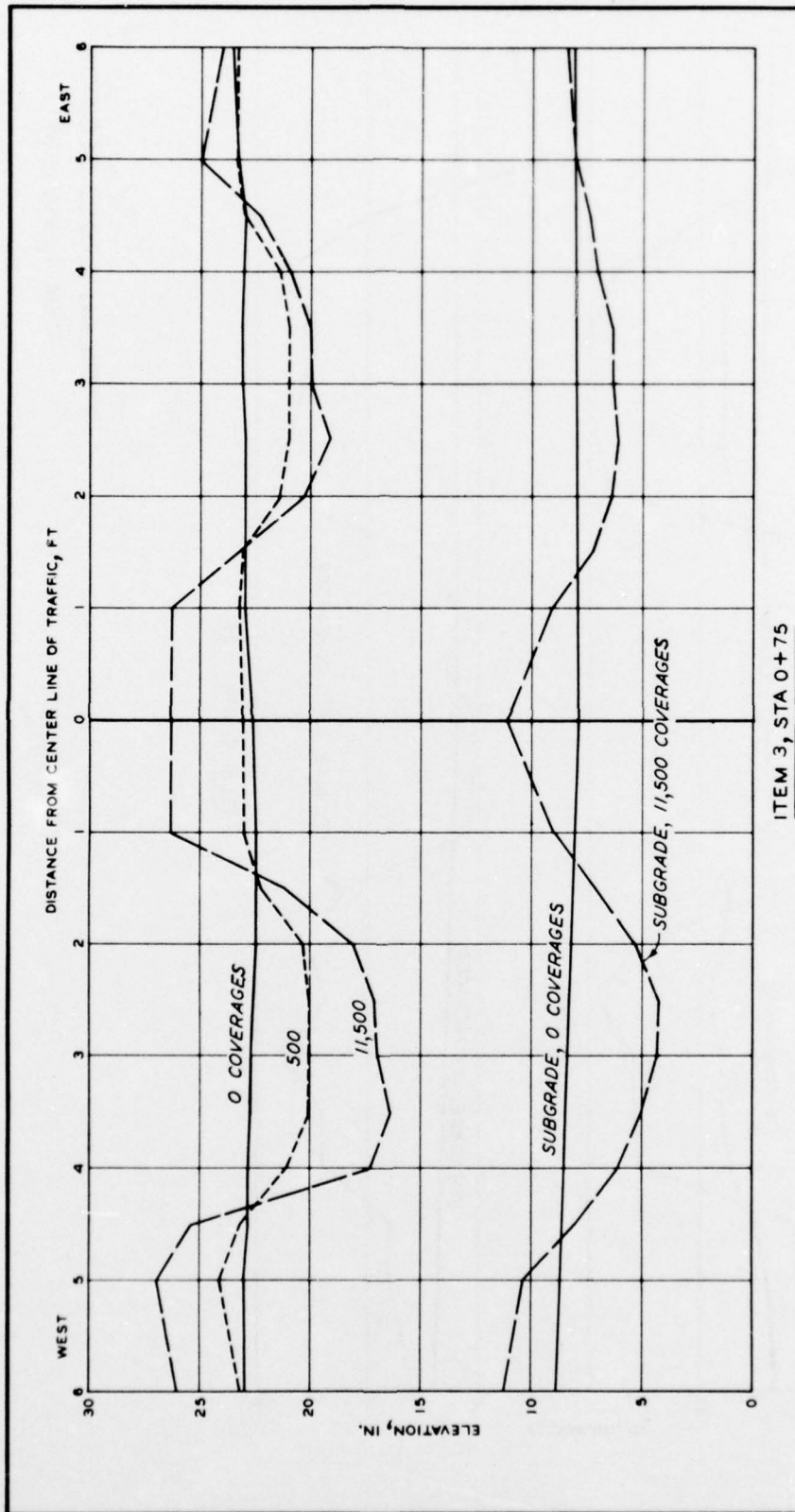


PLATE 2





TYPICAL CROSS SECTION
ITEM 3, STA 0+75

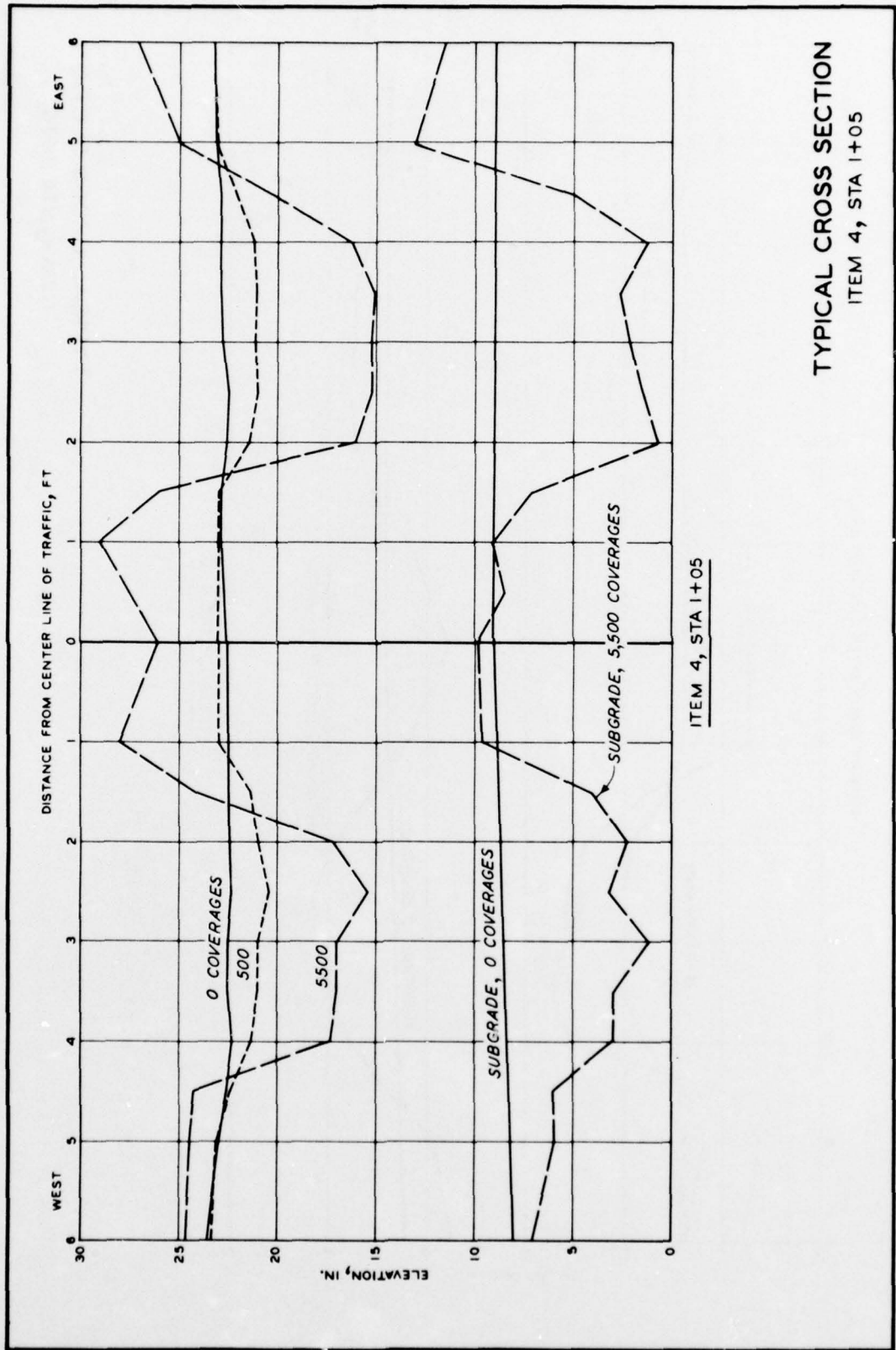
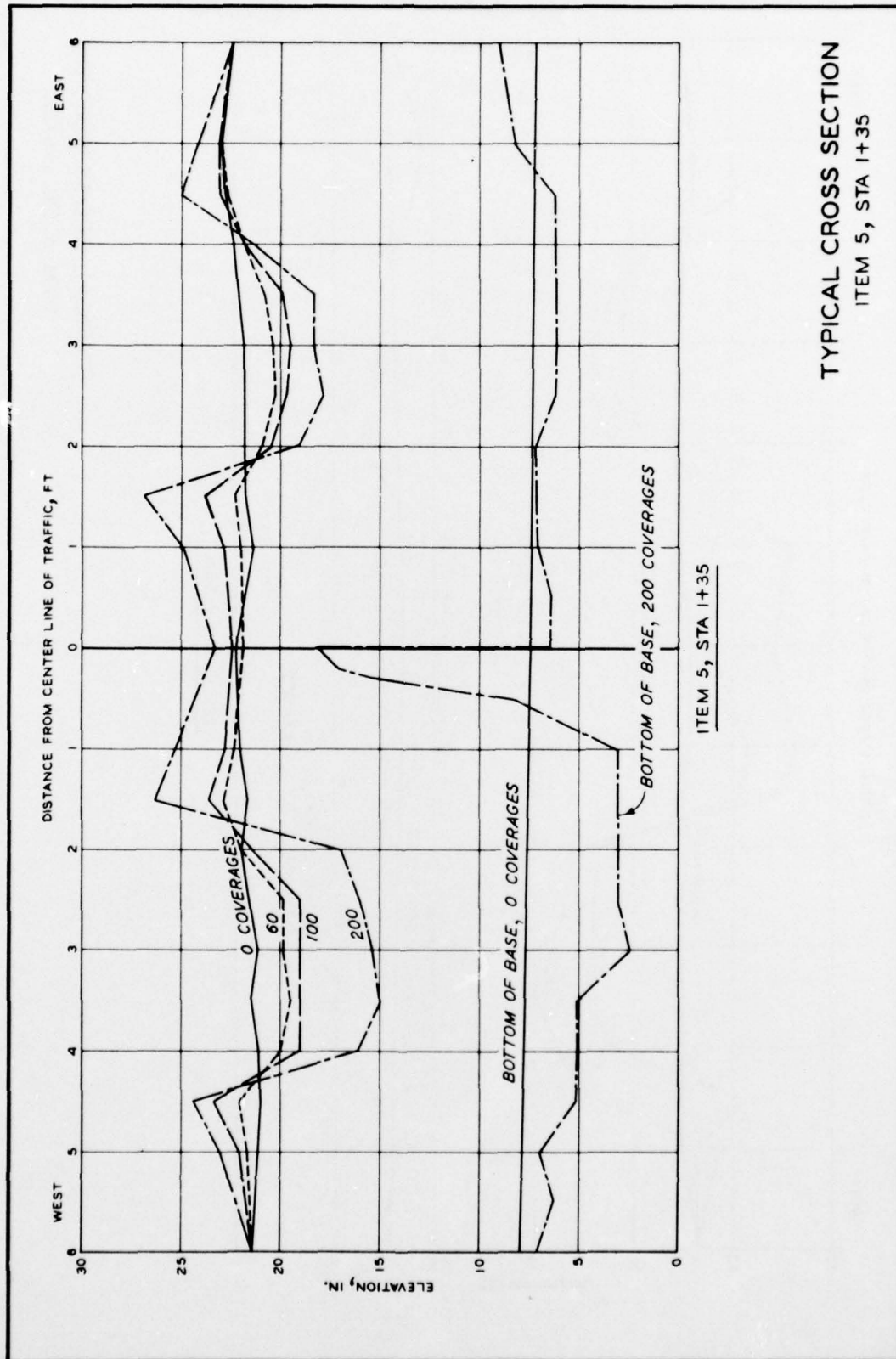


PLATE 6

TYPICAL CROSS SECTION
ITEM 4, STA 1+05

ITEM 4, STA 1+05



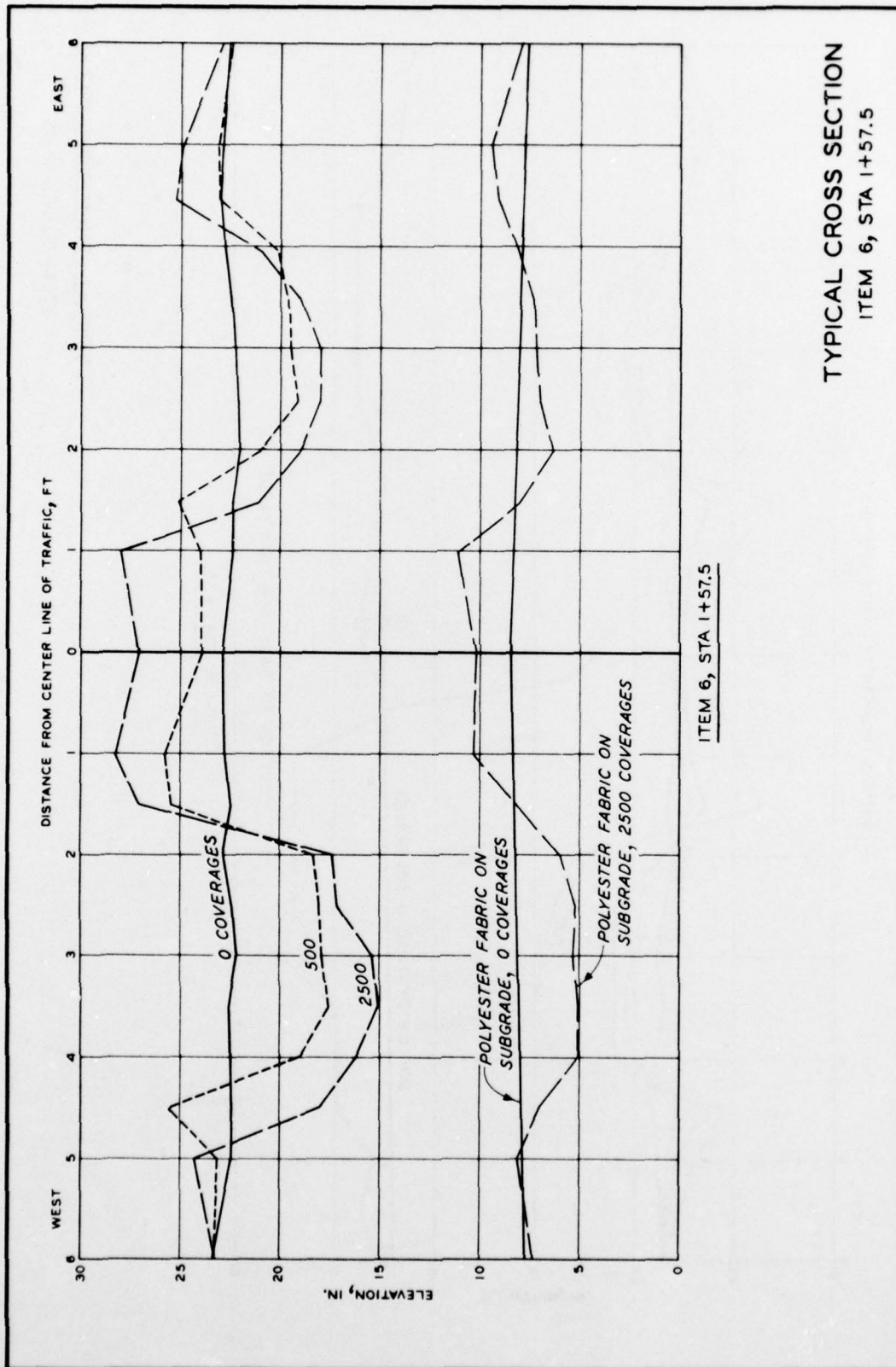
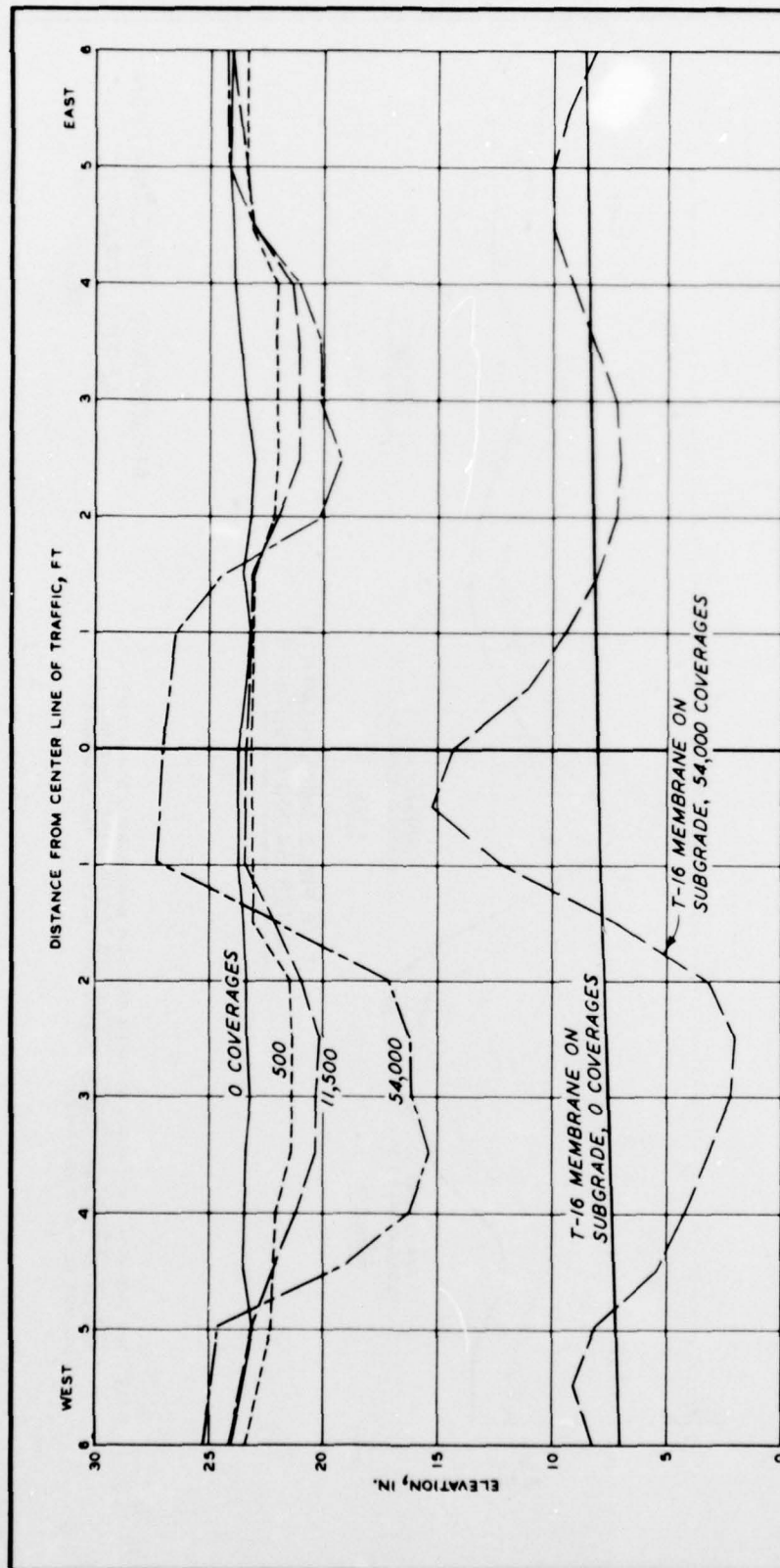


PLATE 8



ITEM 7, STA 1+87.5

TYPICAL CROSS SECTION ITEM 7, STA 1+87.5

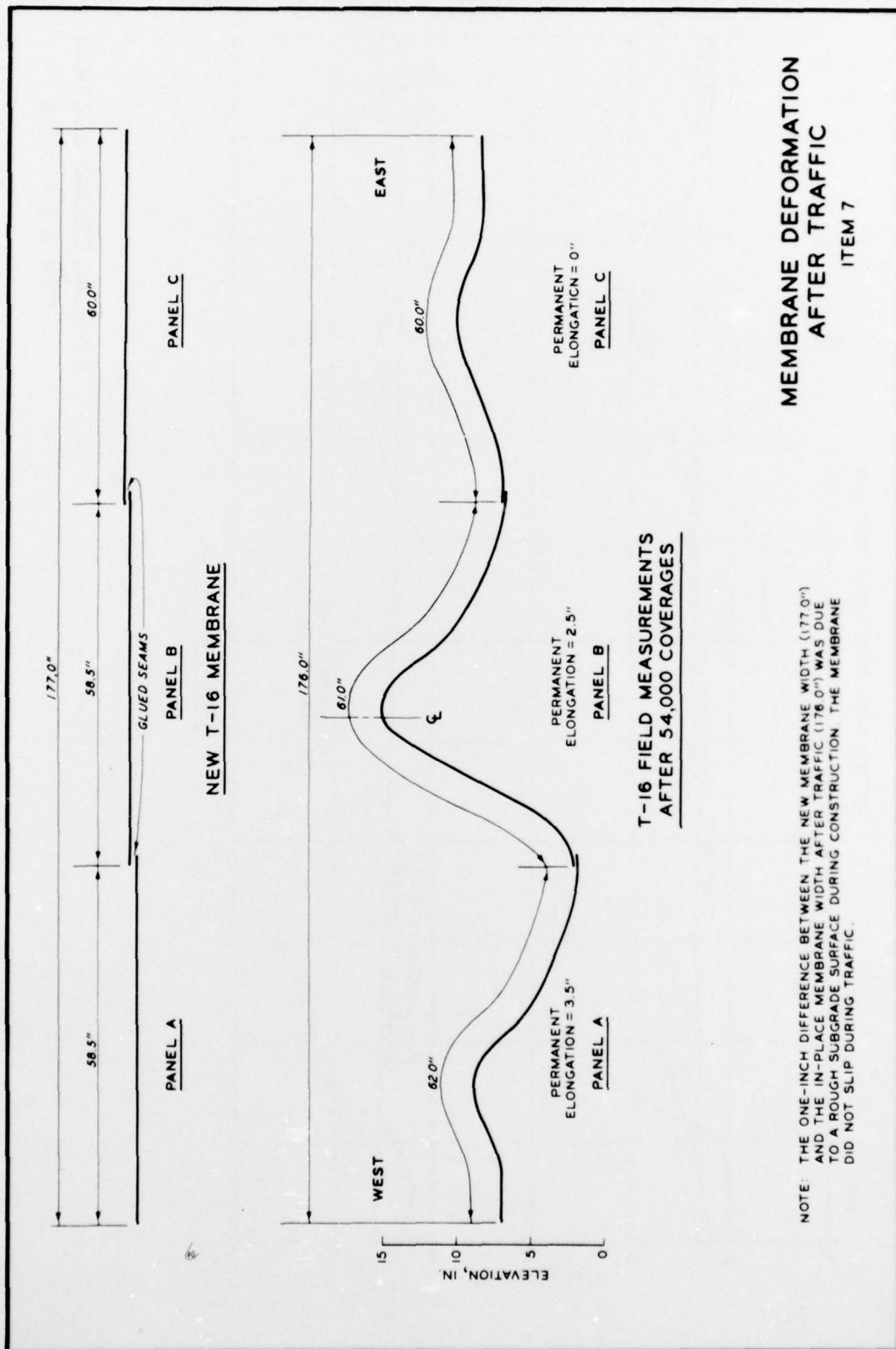
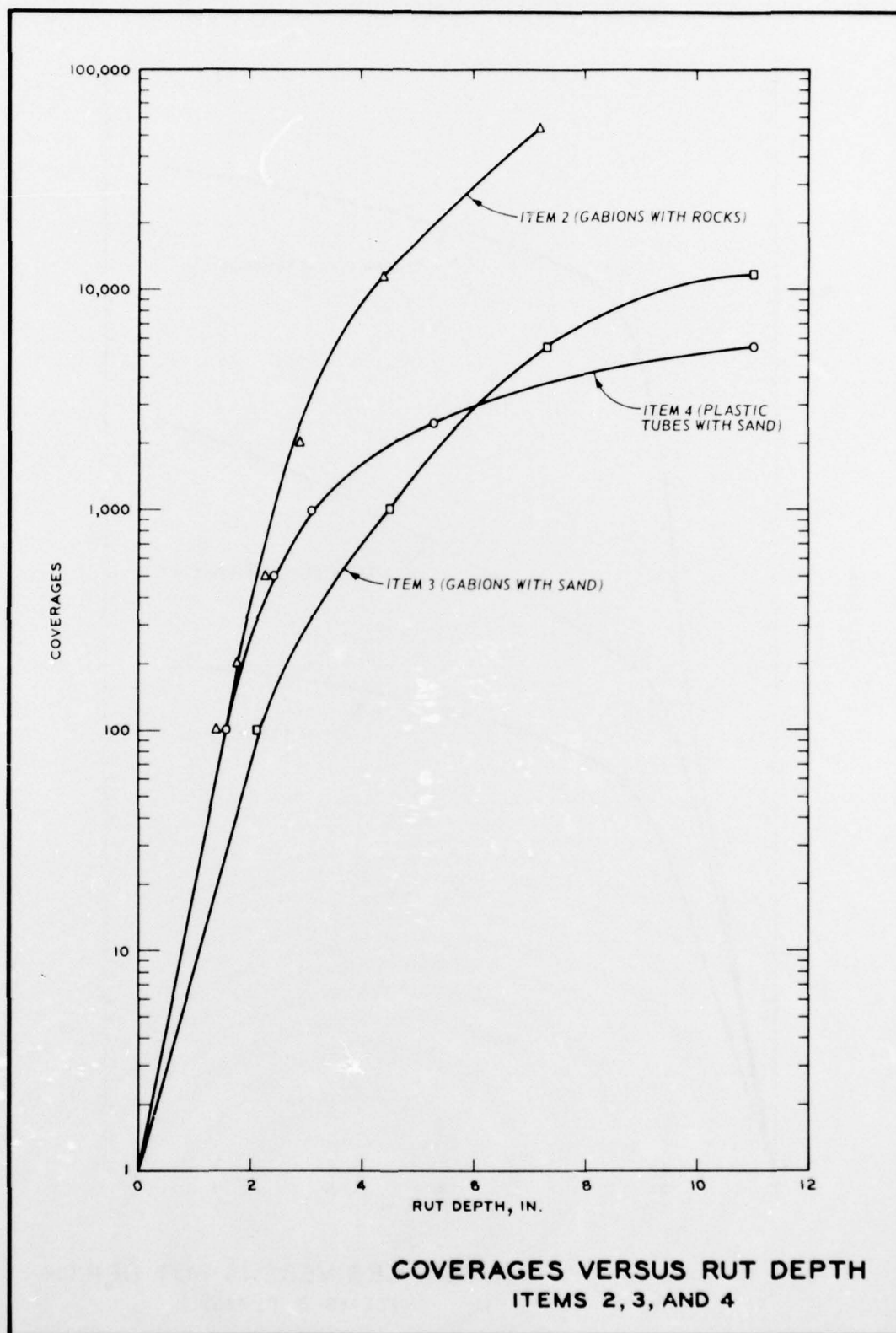
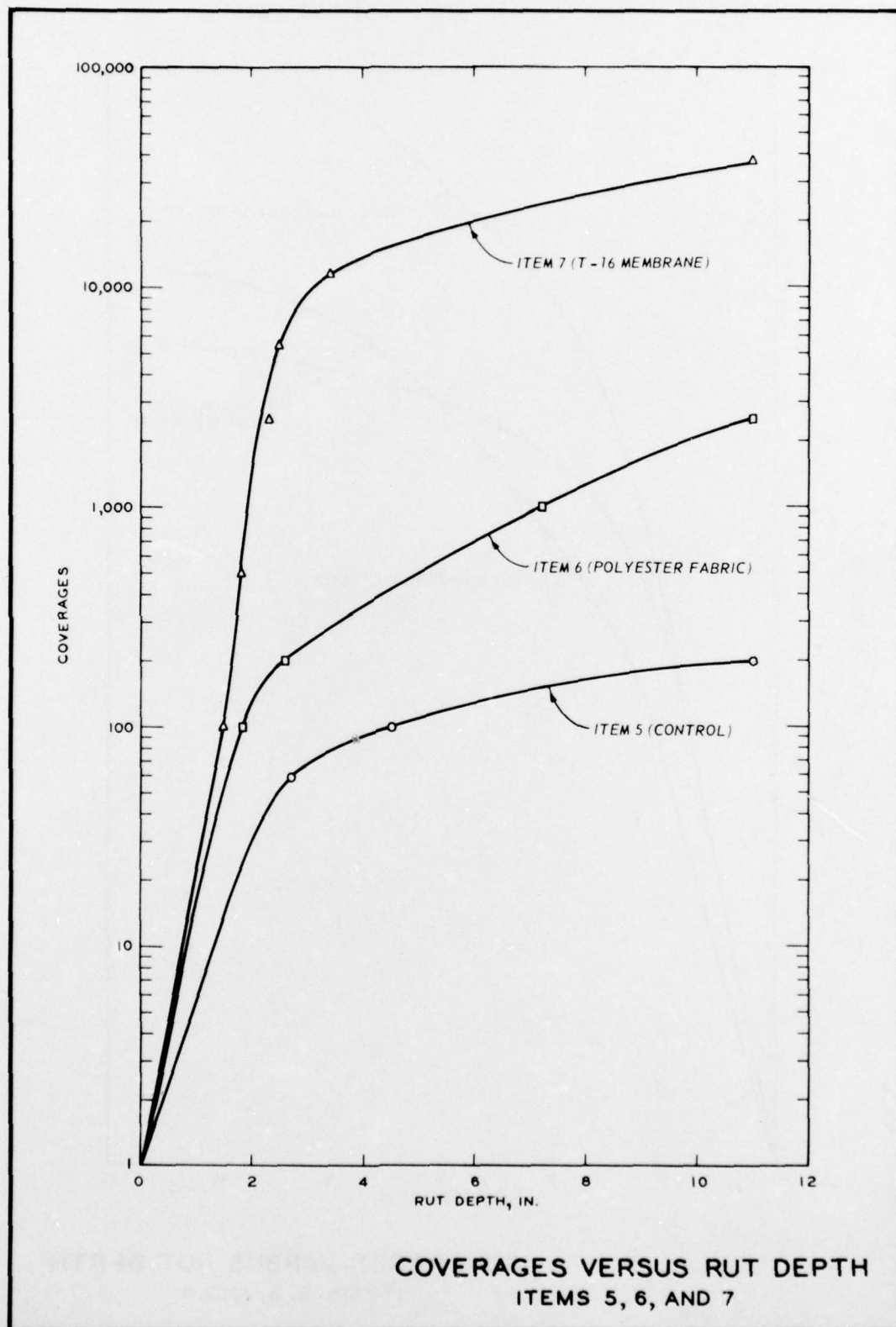
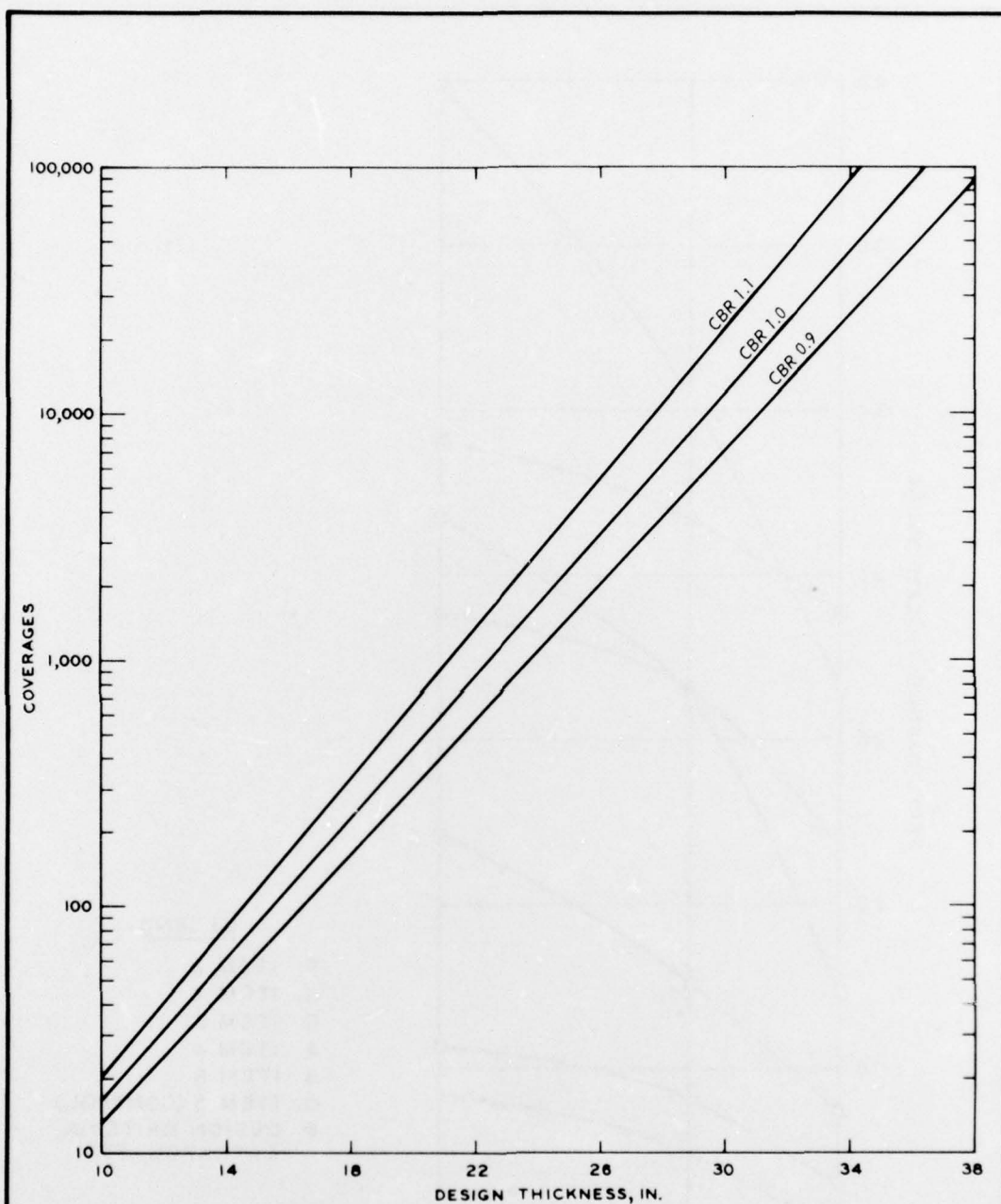


PLATE 10

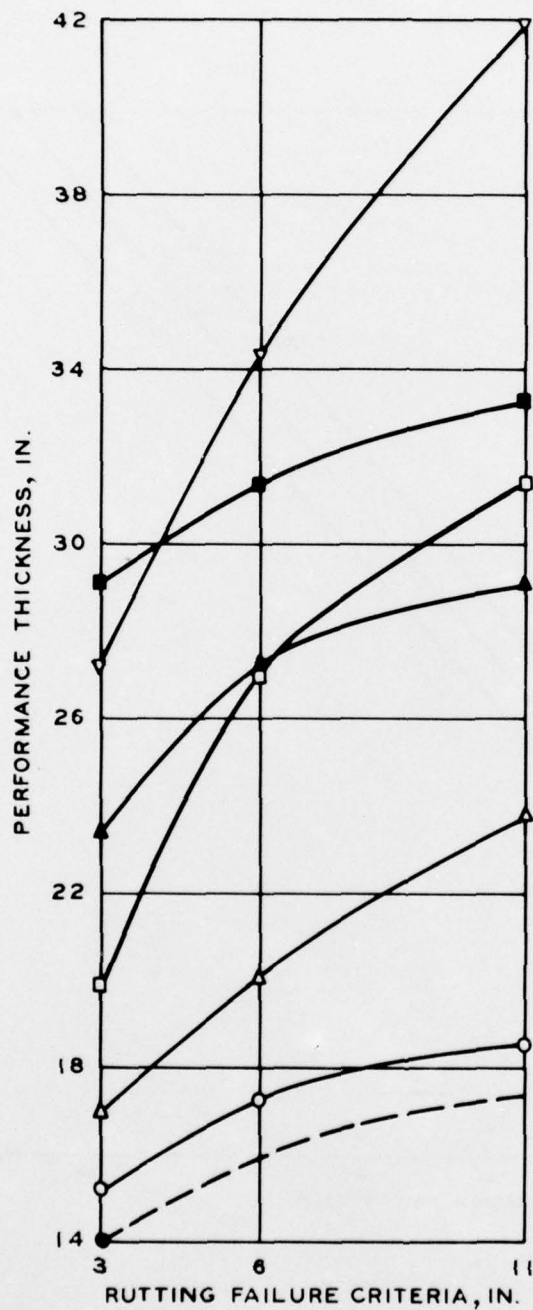






**COVERAGES VERSUS DESIGN
THICKNESS FOR UNSURFACED ROADS**

**18-KIP SINGLE-AXLE
DUAL-WHEEL LOAD**



LEGEND

- ▽ ITEM 2
- ITEM 7
- ITEM 3
- ▲ ITEM 4
- △ ITEM 6
- ITEM 5 (CONTROL)
- DESIGN CRITERIA
EXTRAPOLATED

TEST SECTION
PERFORMANCE

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3. Bridge approaches. 4. Membranes (Roads). 5. Soft soils. 6. Subgrades. 7. Trafficability. I. Watkins, James E., joint author. II. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report S-77-1)
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